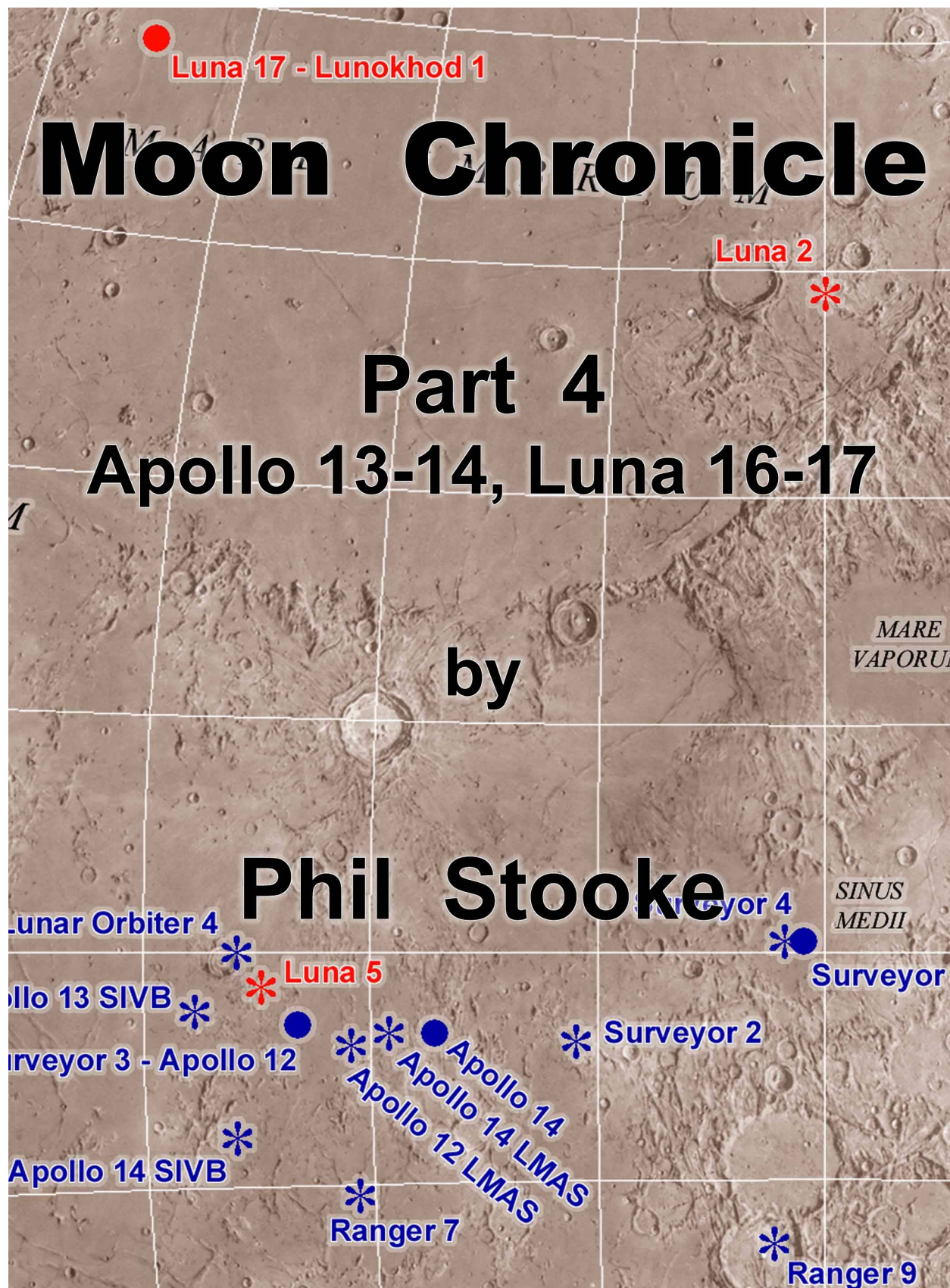




Moon Chronicle

Part 4:
Apollo 13-14, Luna 16-17

by

Phil Stooke

Introduction

The Apollo program had experienced a disastrous capsule fire with loss of the Apollo 1 crew on 27 January 1967. In the period covered by this section of the Chronicle it suffered another potentially catastrophic and very public accident during the flight of Apollo 13. Heroic efforts brought the crew back to Earth safely after a flight around the Moon and the audacious project moved ahead with Apollo 14 only 9 months later. Site selection work continued for the remaining Apollo landings throughout this period.

The Soviet Union was still striving to match American accomplishments at the Moon, and this period saw its robotic program make its greatest gains. The final Zond mission, Zond 8, concluded their attempt to develop a human lunar flight capsule, but this project evolved into the Soyuz capsules used for many years for space station missions. With the Luna 16 mission a new type of lander successfully collected lunar regolith samples and returned them to Earth. Luna 17 delivered a rover to the lunar surface: Lunokhod 1. This vehicle could be driven from Earth and had the ability to survive the lunar night, allowing for long missions of exploration. With sample return missions and rovers the Soviet Union could now boast capabilities resembling those of Apollo at much lower cost and without danger to human life. The scale of these achievements and their scientific results were not really comparable but the Soviet scientists and engineers saved face and the argument had some propaganda value.

This section of the Chronicle concludes with several studies of future lunar operations on a breathtaking scale, but all involved now knew that they would not occur or would be postponed for many years. Project Apollo was already winding down, even as its greatest missions lay ahead.

The missions which reached the Moon are listed in a table and illustrated on a map in an appendix at the end of this volume of the Chronicle.

Spacecraft image credits:

Lunar Reconnaissance Orbiter camera (LROC) data: NASA/GSFC/Arizona State University, and Robinson, M.S., *et al.* (2010). Lunar Reconnaissance Orbiter Camera (LROC) Instrument Overview, *Space Science Reviews*, v. 150, pp. 81-124. <https://doi.org/10.1007/s11214-010-9634-2>

Lunar Reconnaissance Orbiter Laser Altimeter (LOLA): Smith, D.E., Zuber, M.T., Jackson, G.B. *et al.*, 2010. The Lunar Orbiter Laser Altimeter investigation on the Lunar Reconnaissance Orbiter mission. *Space Science Reviews*, v. 150, pp.209-241. <https://doi.org/10.1007/s11214-009-9512-y>

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6 February 1970: Luna 1970A

This Soviet mission was another attempted robotic sample return mission similar to Luna 15 and the ultimately successful Luna 16. The mission launched from Baikonur but the launch vehicle failed to place the spacecraft in Earth orbit. The landing target was probably somewhere in the Mare Crisium or Mare Fecunditatis areas targeted by Lunas 15 and 16.



6 February 1970: Group for Lunar Exploration Planning

The Group for Lunar Exploration Planning (GLEP) met on 6 and 7 February in Houston to review landing site assignments. Much thought was given at about this time to the use of the electric-powered rover which would be ready for the later J-series missions. GLEP recommended that on missions carrying both a rover and an ALSEP, the ALSEP be deployed first. They also considered the rover's capabilities for extending exploration.

Four experimental sorties were developed by a group including representatives of Bellcomm, USGS, NASA's Marshall Space Flight Center in Huntsville, and Boeing, which had built the rover. They laid out short (600 to 2400 m long) 'sortie legs' on high resolution topographic maps of Fra Mauro, at that time the best mapped site with substantial topographic relief. These legs were combined to create fictitious sorties of about the total length Bellcomm had planned for sites at Marius, Hadley, Copernicus and Tycho. These were used for mission operational studies including estimates of driving times. Examples of Copernicus Peaks and Marius Hills traverse plans based on this fictitious terrain were presented at the GLEP meeting, the Copernicus example covering 10.5 km in 5 hours 40 minutes and that at Marius covering 19.3 km in 5.1 hours. Figures 168A-D show the sortie legs and synthetic traverses, including one at Hadley, from Benjamin and Head (1970a). Figures 168E-G show another set of possible traverses by the same authors (Benjamin and Head (1970b) using revised criteria including equipment allowing longer and faster traverses. The faster LRV allowed EVA distances to increase in their examples at Hadley and Marius or added sampling time at Copernicus. The Hadley sites in the two studies were not the same, and neither of them was the one eventually selected. The traverses were intended to cover a range of surface slopes and roughness conditions, not to be realistic science traverses, and often included very unlikely paths up or down steep slopes.

Fra Mauro was now the highest priority Apollo site as it promised material older than the Apollo 11 and 12 lavas, consisting of debris excavated from a considerable depth by the impact which formed the Imbrium basin. GLEP favoured the Davy crater chain (Figure 169A, B) for the H4 mission as it might provide volcanic material from deep sources, but it wanted to land as close to the highland terrain as possible to permit sampling highland material. This is the same site referred to as 'Davy Rille' in other documents. Catena Davy is the name now in use. If Davy was not practical, Censorinus was preferred. They recommended that the Hadley (J-4) site be moved from the west side of the Rille to the east side near Hadley C (site 3 in Figure 178C), giving access to the Apennine Mountains and samples of more than one type of material. The Apollo 12 LM ascent stage impact had provided interesting seismic data, so GLEP recommended that the much larger Saturn IVB upper stage should be impacted on all remaining missions.

Benjamin, P. and Head, J. W., 1970a. LRV design evaluation traverses - cases 320 and 340. Bellcomm memorandum B70 01016, 13 January 1970. NASA-CR-108851, N79-73402.

Benjamin, P. and Head, J. W., 1970b. Implications of revised EVA capabilities on traverse envelopes. Cases 320 and 340. Bellcomm memorandum B70 02078, 26 February 1970. NASA-CR-112695, N79-73081.



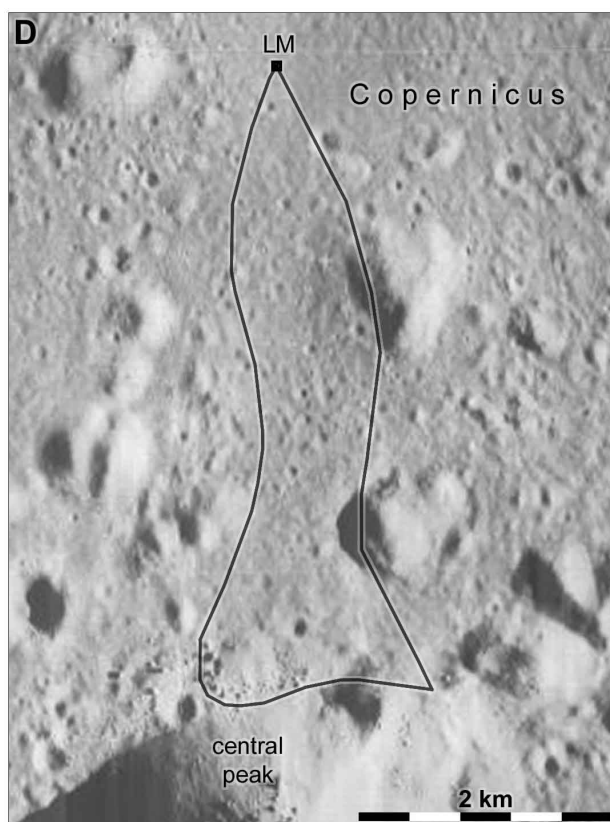
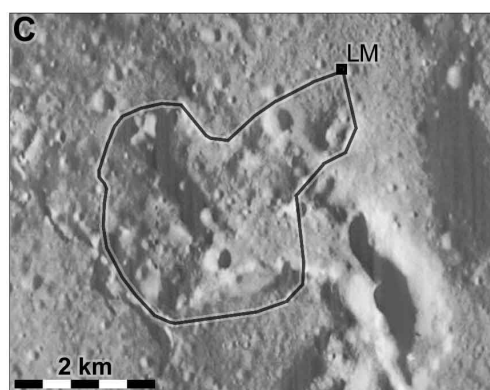
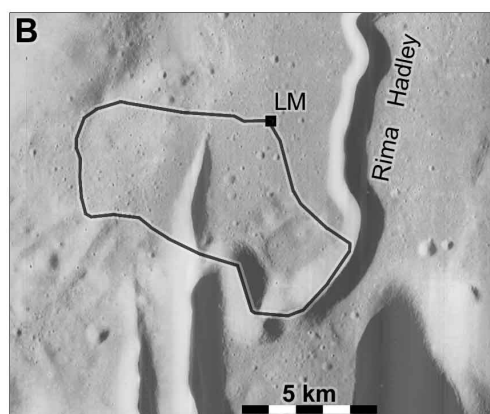
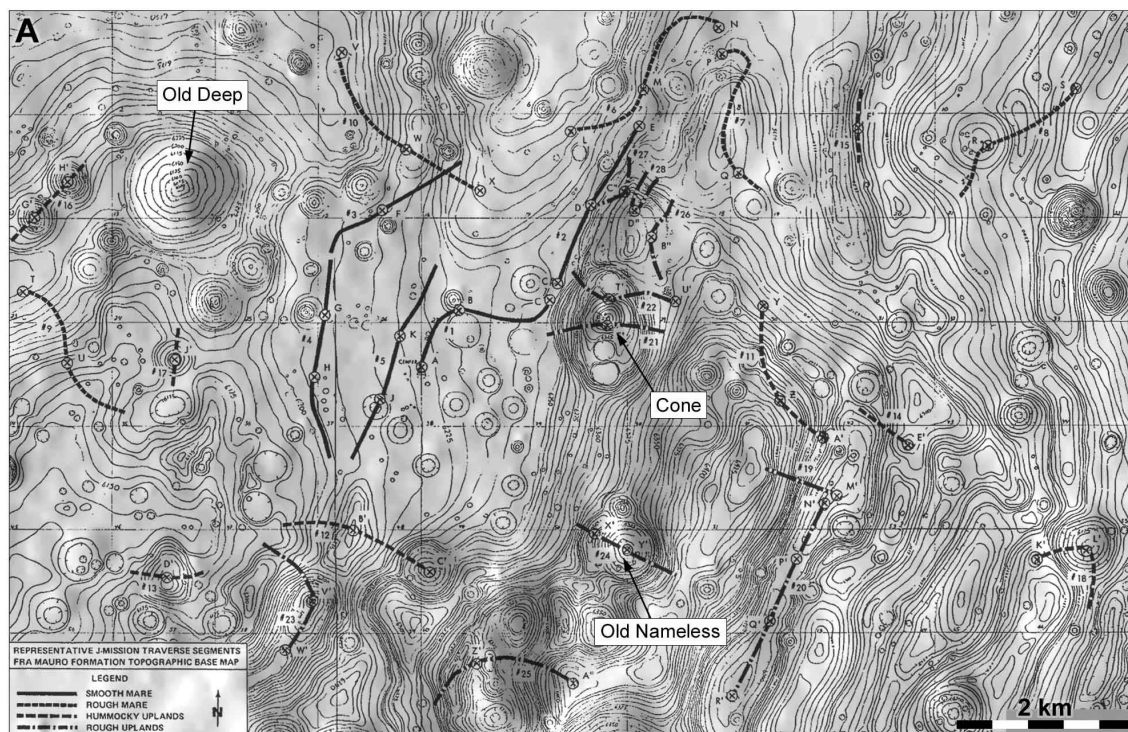


Figure 168 (across two pages). Rover route planning studies (Benjamin and Head, 1970a, b). A: topographic map of the Fra Mauro region showing the route segments used to compile synthetic traverses, reproduced from Benjamin and Head (1970a) and superimposed on an LRO mosaic. B: traverse at Hadley Rille. C: traverse at Marius Hills. D: traverse at Copernicus. B-D are plotted on Lunar Orbiter 5 images.

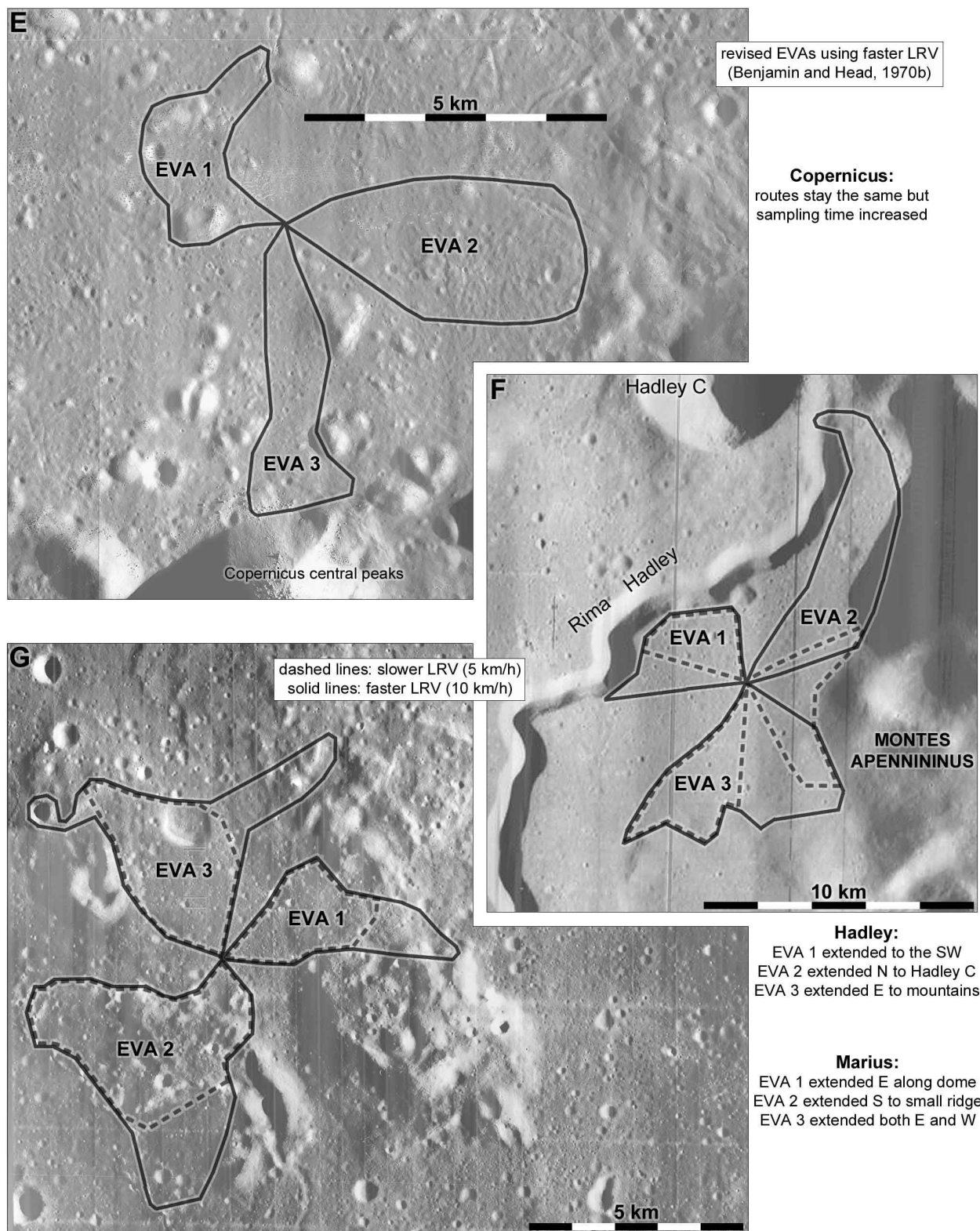


Figure 168 (continued). Rover route planning studies (Benjamin and Head, 1970a, b). Revised routes based on modified LRV and equipment (Benjamin and Head, 1970b). E: traverses at Copernicus. F: traverses at Hadley. G: traverses at Marius Hills. E-G are plotted on Lunar Orbiter 5 mosaics.

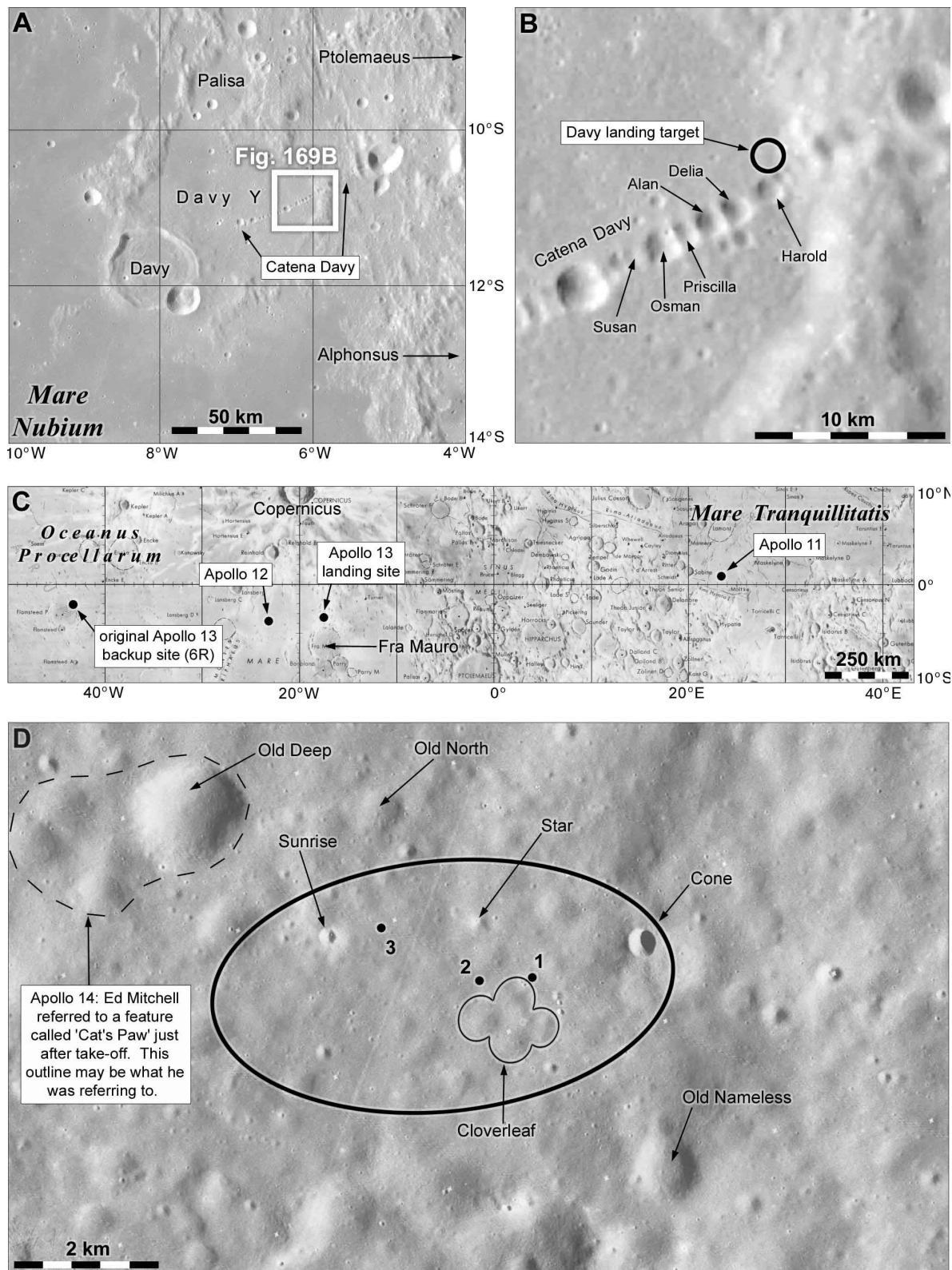


Figure 169: Landing sites at Davy and Fra Mauro. A: potential landing region at Davy Catena. B: Davy Catena landing site. C: Apollo 13 prime and original backup sites. D: The Apollo 13 landing area and three possible landing sites.

19 February 1970: Luna 1970B

This mission by the Soviet Union launched from Baikonur but crashed into the Pacific Ocean after a launch vehicle failure. It is thought to have been a lunar orbiter mission designed to photograph the lunar surface, perhaps similar to the later Luna 19. The resolution of Luna 19 images was not sufficient to plan potential landing sites, so it seems more likely that these orbiters were testing instruments for future planetary missions rather than for landing site selection or scientific study of the Moon.



6 March 1970: Apollo Site Selection Board

By this time the number of remaining flights was beginning to shrink. A Saturn 5 launch vehicle was needed for Skylab, the only surviving part of the once more ambitious Apollo Applications Project. The assembly line was shut down and no new Saturns would be built, so Apollo 20 was cancelled in January 1970 to free a booster for Skylab.

At this meeting the Fra Mauro site for Apollo 13 was confirmed, and attention passed to subsequent missions. A site giving access to volcanic material originating deep in the lunar crust ('deep-seated material') was the priority for Apollo 14, and Littrow was preferred. Davy was preferred over Censorinus for Apollo 15, if both the crater chain and the adjacent highlands were accessible to astronauts on foot. Otherwise Censorinus was preferred. The first Lunar Rover Vehicle (LRV) was expected to fly on Apollo 16, the first of the advanced 'J' missions, and one list had Copernicus in that flight slot, but ASSB now felt that Copernicus was too rough for the first rover. ASSB now had a reduced number of flight slots to allocate to its targets, and reworked the lists again (Table 54). The Board also considered Tycho, Hyginus and an unspecified old highland site, if one could be identified in future Apollo orbital photography.

Table 54. ASSB Site Recommendations, 6 March 1970		
Mission	GLEP Recommendation	MSC Recommendation
H-2 (13)	Fra Mauro	Fra Mauro
H-3 (14)	Littrow	Littrow
H-4 (15)	Davy Rille	Davy Rille or Censorinus
J-1 (16)	Marius Hills	Copernicus
J-2 (17)	Descartes	Descartes
J-3 (18)	Copernicus	Marius Hills
J-4 (19)	Hadley/Apennine	Hadley/Apennine



11 April 1970: Apollo 13

Apollo 13, NASA's third lunar landing mission, was intended to land at Fra Mauro, but an accident during the cruise to the Moon crippled the spacecraft and the landing was cancelled. Extraordinary efforts by the astronauts and mission controllers in Houston eventually brought the crew around the Moon and safely back to Earth. The Apollo 13 crew consisted of Commander James A. Lovell, Jr., who had flown previously on Gemini 7, Gemini 12 and Apollo 8, Command Module Pilot John L. Swigert, Jr., and Lunar Module Pilot Fred W. Haise Jr. The backup crew

consisted of Commander John W. Young (also flew on Gemini 3, Gemini 10, Apollo 10, and later on Apollo 16, STS-1 and STS-9), Command Module Pilot John L. Swigert (Thomas K. Mattingly was the original CMP, but was replaced by Swigert only 72 hours before launch as Mattingly had been exposed to Rubella), and Charles M. Duke (also flew on Apollo 16). The Command Module was called 'Odyssey', and the Lunar Module 'Aquarius'.

Apollo 13 was launched on a Saturn V from pad 39A at Kennedy Space Center on 11 April at 19:13 UT into an Earth parking orbit. At 21:54 UT the SIVB upper stage Trans-Lunar Injection burn sent the spacecraft towards the Moon. The CSM separated from the SIVB, turned, docked with the LM in its housing, and extracted it from the SIVB. Then for the first time on an Apollo flight the S-IVB auxiliary propulsion system burned at 01:13 UT on 12 April to place the SIVB on a trajectory which would impact on the Moon, to provide a seismic signal for the Apollo 12 seismometer. It struck the lunar surface on 14 April at 01:09 UT at 2.75° S, 27.86° W with a velocity of 2.58 km/s (Figure 173). Odyssey made a mid-course correction burn on 13 April at 01:27 UT.

On 14 April at 03:06 UT Jack Swigert switched on fans to stir oxygen in tanks in the Service Module. Wires previously damaged during pre-flight testing in one tank shorted, causing a fire which led to an explosion two minutes later. The interior of the Service Module was severely damaged, the Command Module rapidly lost power, and very quickly the mission was aborted and the crew transferred to the Lunar Module which now had to function as a 'lifeboat'.

At 08:43 UT a mid-course correction was made by the Lunar Module descent stage engine, placing the spacecraft on a free-return trajectory around the Moon and back to Earth. Apollo 13 looped around the Moon, allowing the astronauts to take some lunar photography (Figure 174). The maximum distance from Earth on this orbit was 400171 km, greater than any other Apollo crew had flown and still a record for human flight until the Artemis era five decades later. Another Lunar Module engine burn on 15 April at 02:41 UT shortened the return time, as reserves of power were extremely limited. To conserve power and other consumables the lunar module was powered down except for environmental control, communications, and telemetry, and passive thermal control was established. At 04:32 UT on 16 April, and again at 12:53 UT on 17 April, two more small burns adjusted the return geometry.

The Service Module was jettisoned at 13:15 UT on 17 April and the crew was able to see and photograph the damage. The Command Module was powered up and the Lunar Module was jettisoned at 16:43 UT. Apollo 13 splashed down in the Pacific Ocean at 21° 38' S, 165° 22' W, southeast of Samoa and 6.5 km from the recovery ship USS Iwo Jima, on 17 April at 18:08 UT after a mission lasting 142.9 hours. The Apollo 13 Command Module is now on display at the Kansas Cosmosphere and Space Center, Hutchinson, Kansas.

If Apollo 13 had landed successfully the crew would have deployed an ALSEP and sampled the Fra Mauro Formation, part of the Imbrium Basin ejecta blanket. A Lunar Surface Closeup Camera would have been used as on the two previous landing missions to take stereoscopic photographs of small features. Orbital photography would have included high resolution 'bootstrap' coverage of proposed landing sites at Censorinus, Descartes and Davy. Also, the very bright Comet Bennet (1969 Y1) would have been photographed from lunar orbit. Because of the accident, only two Hasselblad 70-mm cameras and two automatic data acquisition cameras were used, providing 584 70-mm frames and some distant frames of 16-mm photography during the return coast. After the landing and return from the surface, the Lunar Module Ascent Stage (LMAS) would have been crashed to provide a new seismic signal for the Apollo 12 and 13 seismometers. According to the Apollo 13 Final Flight Plan the Apollo 13 LMAS was to be targeted at 3.0° S, 19.65° W (Figure 172), but if the Apollo 13 ALSEP was not functioning properly the impact would be targeted near the Apollo 12 site at 3.32° S, 23.38° W, close to the Apollo 12 LMAS target (Figure 166).

Figure 169C locates the Apollo 13 landing site relative to the Apollo 11 and 12 sites. It also shows Apollo site 6R, the Flamsteed Ring site being considered as a backup when Table 50 was produced. By the time of flight the requirement for a backup landing site had been dropped in favour of a different approach. There would be only one site. The crew would be launched a day early and spend that extra day in lunar orbit before landing. A launch delay could be accommodated by omitting the extra time in orbit. A further delay would result in landing with a higher Sun than previously allowed. This reduced the training demands on the crew and simplified planning.

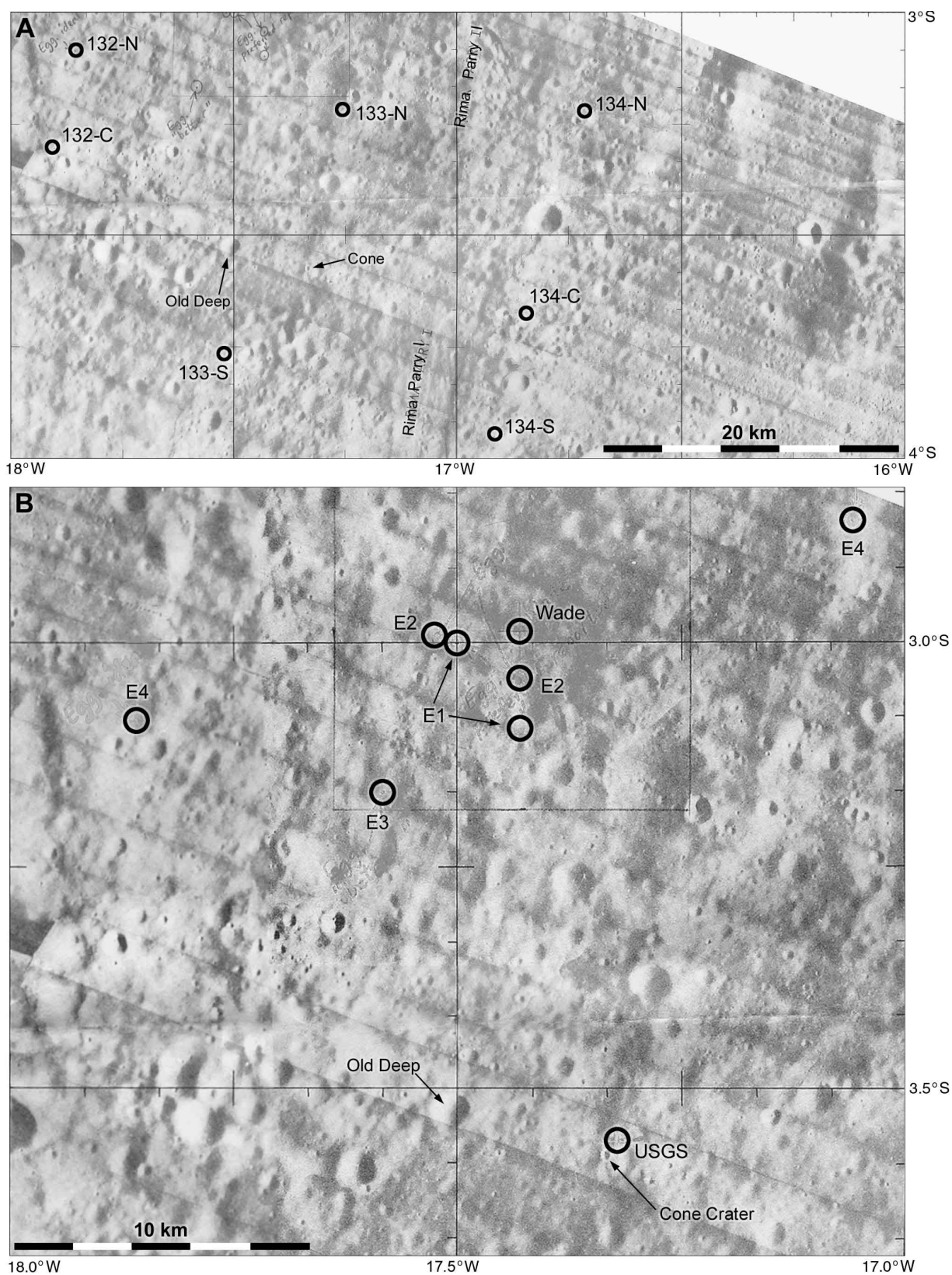


Figure 170: Apollo 13 site selection, reproduced from materials provided by Don Wilhelms to USGS Flagstaff. The sites are described in the text.

The Apollo 13 landing ellipse, shown in Figure 169D based on ASSB presentation materials from the most recent meeting, was almost the same as that first considered in 1968 (Figure 113A, B, which also show the regional context of the site). Many other nearby locations were also considered (Figure 170), but this area was preferred for its wide valley floor and easy access to a ridge and fresh crater (Cone crater) at the eastern end of the ellipse. A few other informal names are also shown. Dots marked 1, 2 and 3 show the three candidate landing points within the ellipse, numbered in order of preference.

The Fra Mauro Formation, the ejecta blanket of the Imbrium basin, was the sampling goal for Apollo 13, but as it covered a very large area a specific target had still to be chosen. The site would be in the region photographed by Lunar Orbiter 3 just north of the crater Fra Mauro itself (Site IIIS-23, Figure 70), as it was in the Apollo zone and was the best photographed example of the desired material. These images had been taken originally in the hope of locating a Surveyor landing site in the region. Within this large area many candidate Apollo landing points might be identified, and a first assessment is recorded in papers deposited by Don Wilhelms in the branch history collection at USGS Flagstaff.

Notes dated 12 July 1969 record seven candidate sites within high resolution image coverage (Figure 170A). The site numbers indicate the Orbiter 3 high resolution frame covering the area. These points provided access to materials of both ridges and valley floors, in case these had different origins, and most are near small fresh craters which should excavate true Fra Mauro material from beneath any later accumulation of crater ejecta. Point 132-C was the 'first priority' site preferred by R. Eggleton in a note of 16 June 1969. Its coordinates were given as 3° 16.0' S, 17° 56.0' W. The 132 designation refers to the Lunar Orbiter 3 frame containing the site.

Notes dated 15 August 1969 follow the selection process. Figure 170B shows sites proposed by Louis Wade and Richard Eggleton. Wade's target was at 2° 59' S, 17° 26' W. Eggleton initially preferred two sites (E1 on the map) at 2° 59' S, 17° 30' W (the map and coordinate positions do not agree in the original and are not corrected here) and 3° 06' S, 17° 26' W. Later he adjusted these positions slightly (E2, plotted on their map as shown here, but with coordinates of 3° 03' S, 17° 31' W in their notes not matching either position). He chose a 'still better' site (E3) at 3° 10' S, 17° 35' W, then jumped to two 'ideal' sites (E4) further away at 3° 05' S, 17° 52' W and 2° 52' S, 17° 03' W.

Meanwhile Farouk El-Baz (Bellcomm) in a memorandum to Capt. L. R. Scherer (NASA) indicated a point selected by USGS on a ridge near a fresh 400 m diameter crater, close to the ellipse examined in 1968 (Figure 113A, B). This point was at 3.559° S, 17.323° W and is labelled USGS on Figure 170B. The fresh crater was the one later called Cone.

By 27 January 1970 (memorandum from F. El-Baz to the GLEP Site Selection Subgroup members), the target had been shifted to the valley floor immediately west of this ridge. This became the final site. Three alternative targets were described, in decreasing priority from east to west because the ridge and fresh crater were sampling priorities. The three targets are identified in Figure 169D, and also in the EVA plans in Figures 171 and 172.

EVAs were pre-planned for each of the three targeted landing sites, more formally than for Apollo 12 since there was more confidence that the landing would be fairly precise. Apollo 14 was directed to this site after Apollo 13 failed to land, but comparison of these plans with those for Apollo 14 (Figure 199) reveals many small differences between the two mission plans. Figure 171A shows the EVA plan for landing site 1, the preferred site. Heavy black lines are the basic EVA routes. Thinner black lines show extensions which could have been attempted if time permitted. Panoramic photography stations are indicated, and squares show the LM and ALSEP locations. Small dots are sampling locations, and the map also includes several informal placenames.

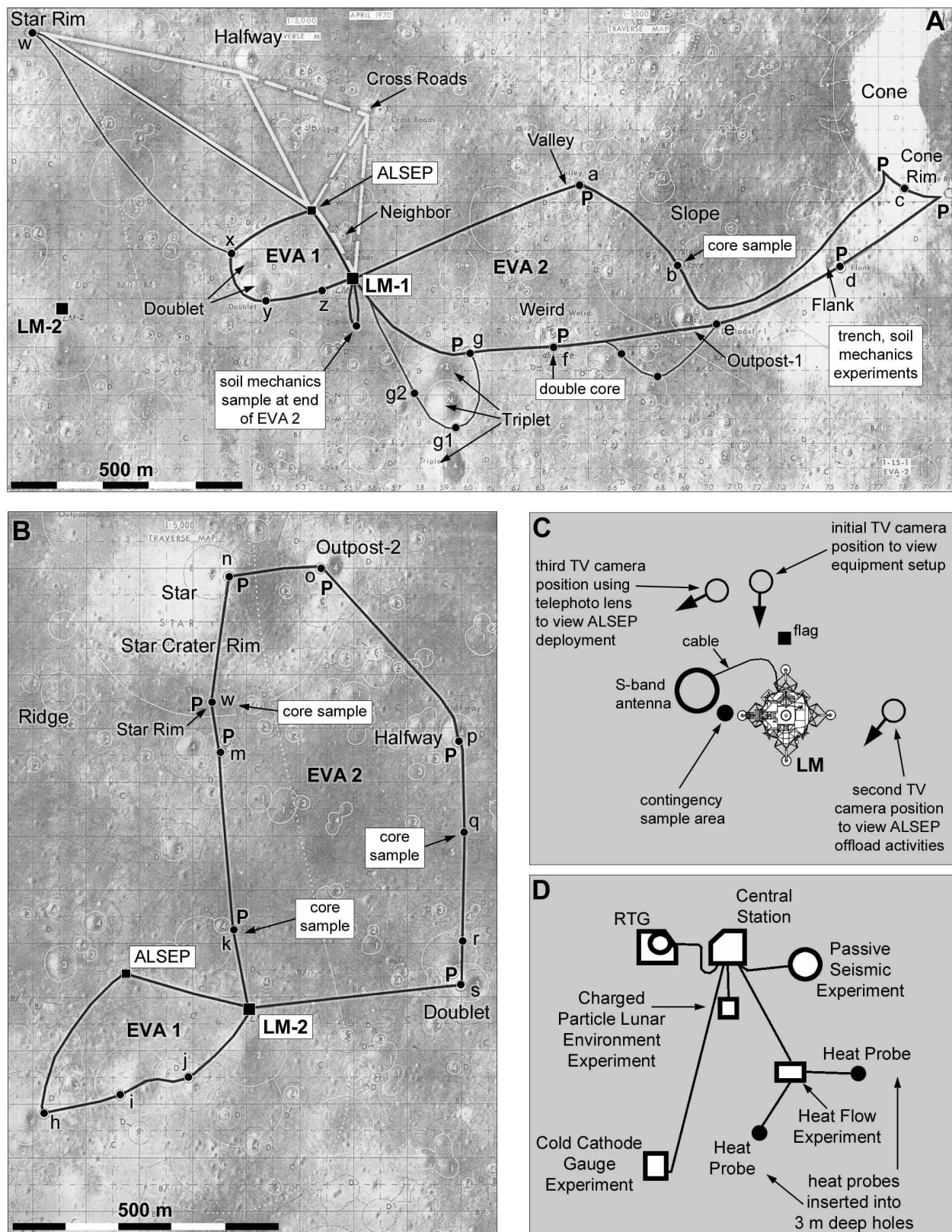


Figure 171: Apollo 13 plans for surface operations. A: EVAs at site 1. B: EVAs at site 2. C: schematic activities near the LM. D: schematic ALSEP layout.

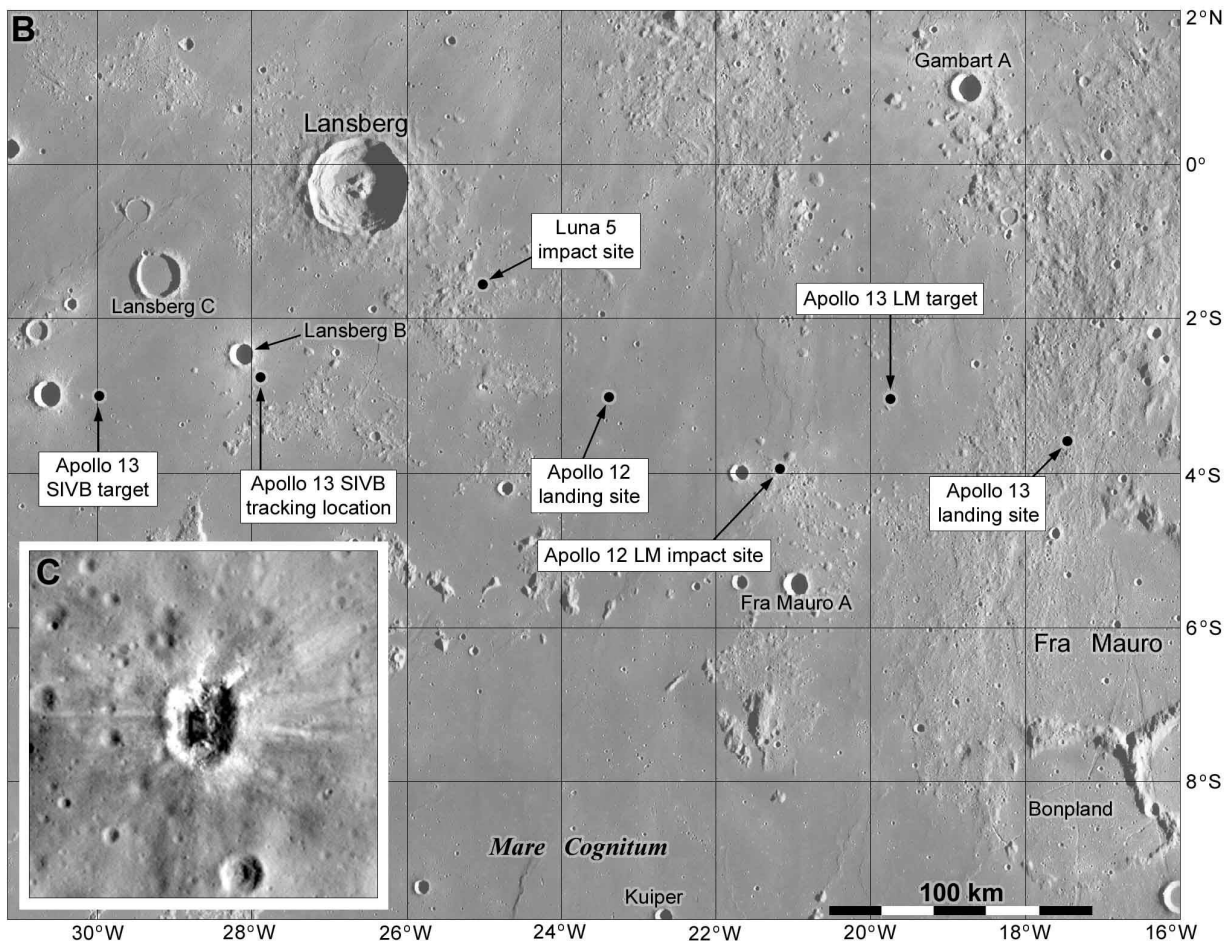
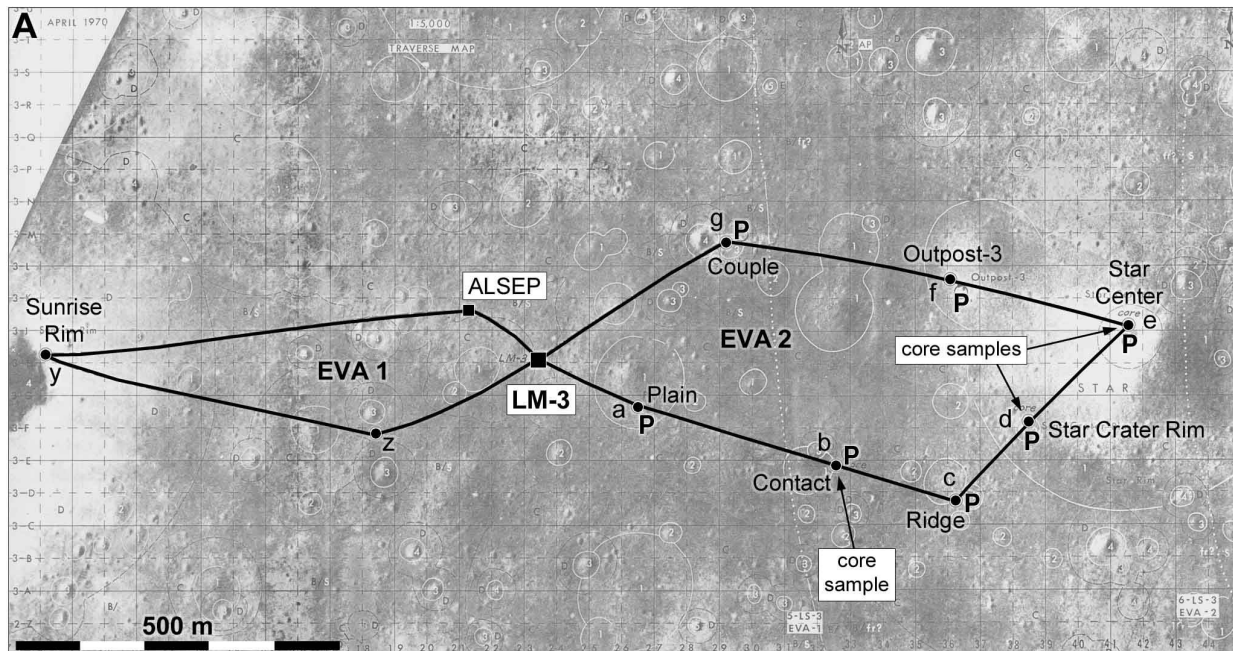


Figure 172. Apollo 13 plans and impact targets. E: EVAs at site 3. F: landing site, LM impact target and SIVB target. G: part of LROC image M160139273L showing the SIVB impact crater.

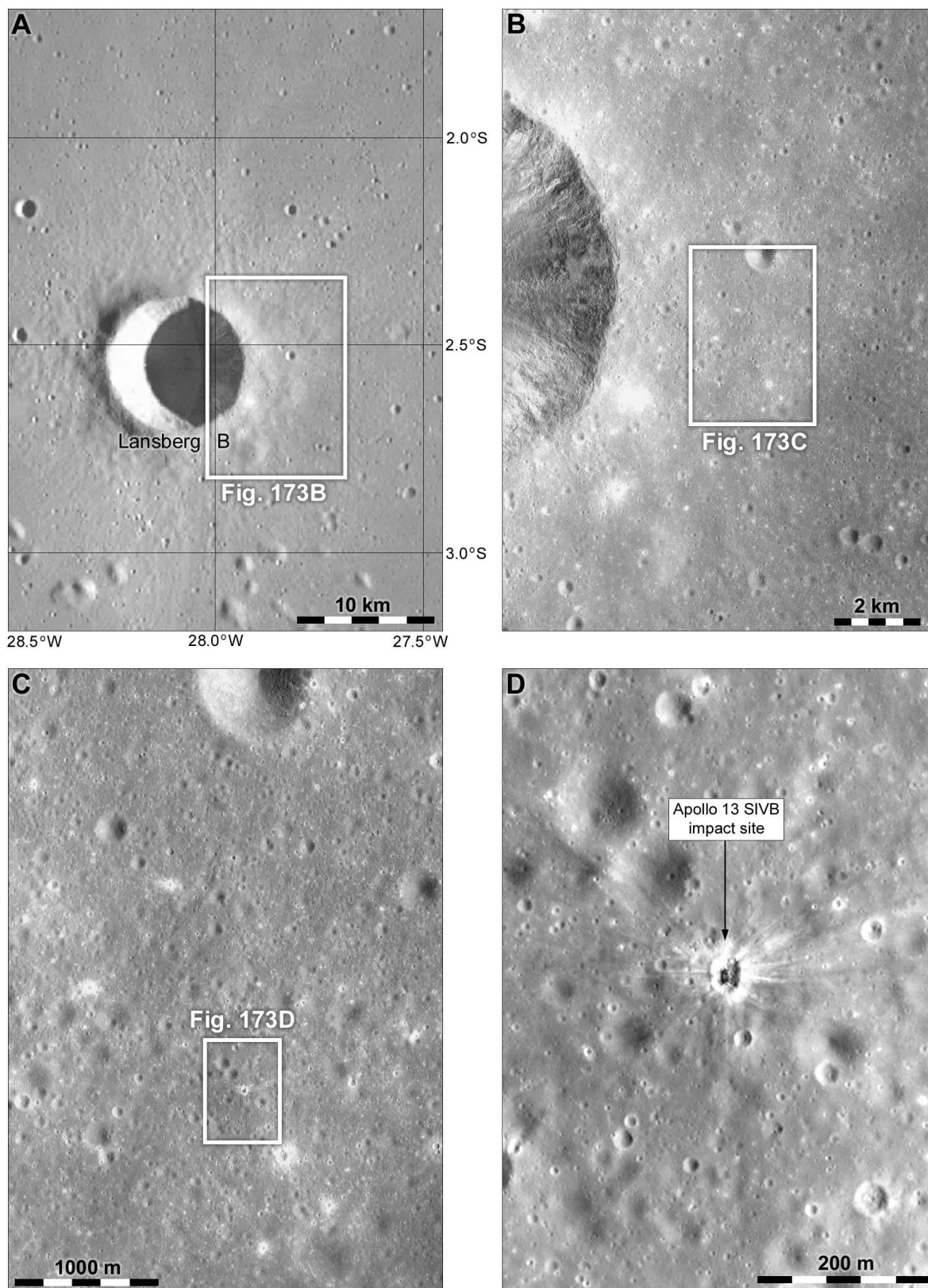


Figure 173. Apollo 13 SIVB impact site. A is an LROC Wide Angle mosaic. B, C and D are parts of LROC image M1121422331L.

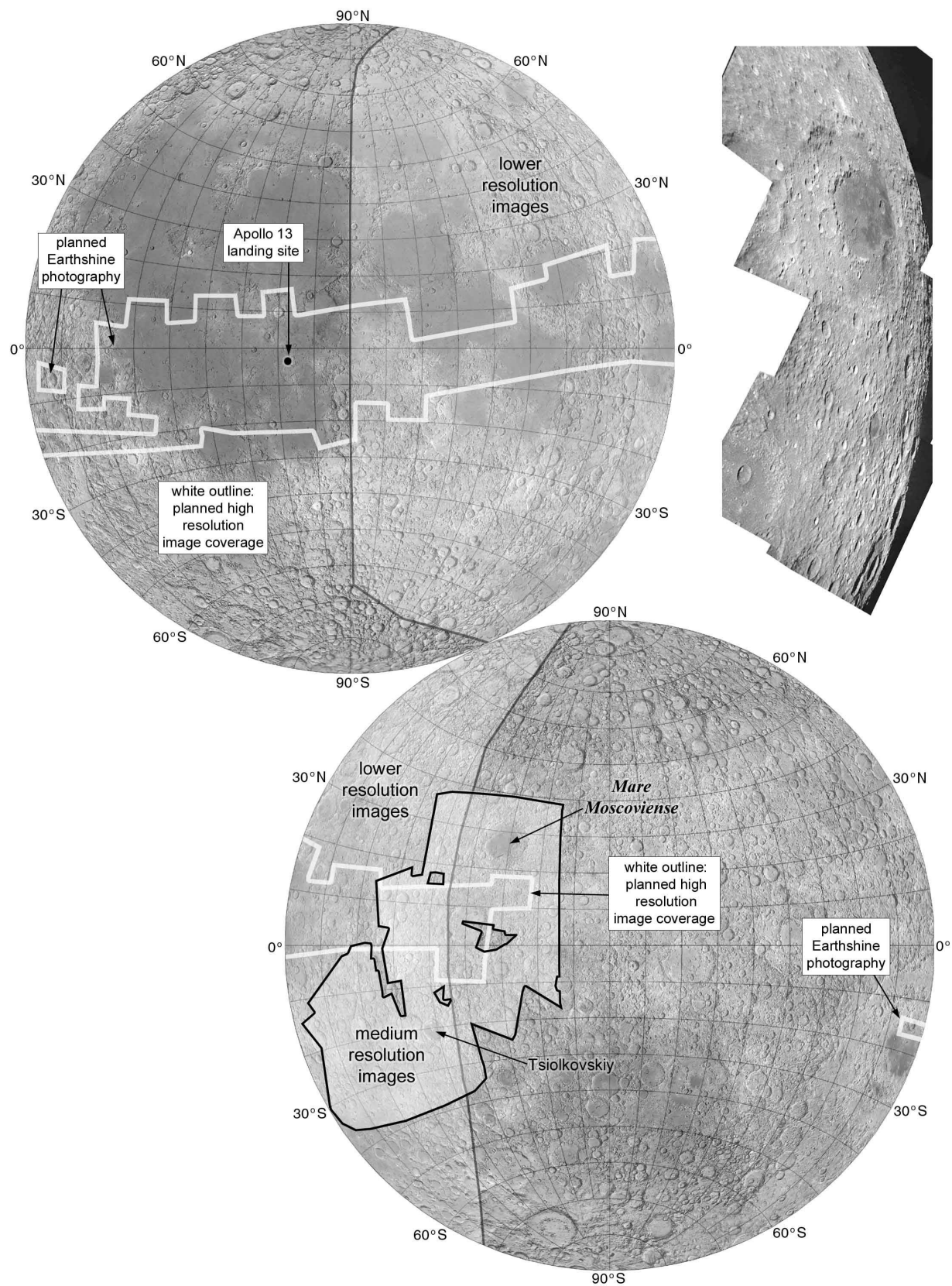


Figure 174. Apollo 13 imaging coverage and planned coverage. Inset at upper right: Mare Moscoviense region.

White lines in Figure 171A show alternate EVAs considered during planning but not included in the official flight plan. The solid white line shows a variation on the possible EVA 1 extension to 'Star Rim', the rim of Star Crater, which would also visit Halfway Crater. The dashed white lines show a different version of EVA 1 altogether. It would involve setting up the ALSEP, then walking to Cross Roads Crater and back to the LM. If time permitted, the trek from the ALSEP to Star Rim to Halfway and then to Cross Roads would be added. These variations appeared in some contemporary news reports. EVA maps are adapted from the Apollo 13 Flight Plan.

Figure 171B shows the Apollo 13 EVA plans for a landing at site 2. Equipment and activities around the Lunar Module are shown in Figure 171C. Apollo 13 carried a large S-band antenna like that on Apollo 12. A contingency sample would be collected near the footpad at the start of the EVA. Then the camera would be moved about 15 m north to view the antenna and flag deployment. A solar wind collector like those flown on Apollo 11 and 12 would also be set up nearby. Then the camera would be moved to view the offloading of the ALSEP equipment packages and the fuelling of the RTG. The plutonium fuel rod was stored separately during flight and only placed in the RTG during the EVA. Finally the camera would be moved to a third position and pointed towards the ALSEP deployment area, using a telephoto lens to give better viewing of the ALSEP site which was 150 to 200 m from the LM (NASA, 1970).

The planned Apollo 13 ALSEP layout is shown in Figure 171D. The Apollo 13 ALSEP was similar to that of Apollo 12, but with a heat flow experiment instead of a magnetometer and a charged particle measuring instrument instead of a solar wind spectrometer (though it would perform a similar function). A drill would be used to emplace the heat flow probes, and then to collect a core sample for return to Earth. The TV camera near the LM would be fitted with a telephoto lens for better monitoring of ALSEP deployment. Some planners advised against carrying an ALSEP on Apollo 13, partly to save weight, allowing more hovering time in case it was difficult to find a level landing point at this hilly site, but also because Fra Mauro is so close to Apollo 12's landing site. Saving the ALSEP for a more distant site would result in better geophysical data.

Figure 172A shows the plans for landing site 3. There was a crater called 'Outpost' at each site. The ALSEP deployment was always scheduled early in EVA 1, followed by a short traverse to collect samples and a longer traverse in EVA 2, similar to the Apollo 12 EVAs.

Figure 172B shows the Saturn IVB upper stage impact target (3° S, 30° W), the target for the Lunar Module ascent stage impact if a normal mission profile had been followed (3° S, 19.75° W), and the Apollo 12 landing and LM impact sites. Control over the SIVB trajectory was limited, so the impact was only expected to be within about 500 km of the target (Apollo 13 Press Kit, NASA News Release 70-50K, 2 April 1970). Tracking suggested the SIVB had crashed at 2.75° S, 27.86° W. An inset (Figure 172C) shows the impact crater.

Ewen Whitaker (Lunar and Planetary Laboratory, University of Arizona) located the 40 m diameter impact crater at 2.54° S, 27.79° W, in photographs taken later by the Apollo 14 crew. The crater was unusual in that it had a halo of mixed bright and dark rays, unlike most natural impact craters. Figure 173 shows the SIVB impact area and the crater with its mixed bright and dark ejecta in progressively greater detail. It lies on the outer eastern flank of the crater Lansberg B (Whitaker, 1972).

Apollo 13's photographic coverage is plotted in Figure 174. The medium resolution images cover Mare Moscoviense and the crater Tsiolkovskiy. Lower resolution images made during the departure from the Moon extend onto the nearside. Because the mission did not spend time in lunar orbit before landing, the landing site itself was not illuminated. White outlines show the planned image coverage, including experimental earthshine photography west of the terminator. An inset in Figure 174 is a mosaic of Apollo 13 images AS13-60-8647 to 8653, extending about 1200 km along the farside terminator from Mare Moscoviense (dark area at top) to the equator.

If the Apollo 13 LM was unable to land, a back-up plan for a CSM-only photographic mission was proposed by the Manned Spacecraft Center (1970). This would apply if the LM could not be extracted from the SIVB or the LM was found to be faulty during trans-lunar cruise, and in either case the LM would not be taken into orbit. The first priority was to collect the already planned bootstrap images in support of future landing site studies. On orbit 4 vertical and oblique images of Censorinus and Moring C would be taken. After an orbit plane change on orbit 12,

similar images of Davy Rille and Descartes would be obtained on orbit 14. Another plane change on orbit 25 would allow imaging of Alphonsus and Gassendi East on orbit 27.

The memorandum also contained a ranked list of 21 landing sites similar to earlier lists but not exactly the same (Table 55). Many of these were outside the area Apollo 13 could observe but they indicate which sites were still of interest to mission planners.

Table 55. Ranked sites for bootstrap photographic coverage, February 1970					
Site	Name	Location	Site	Name	Location
1	Censorinus	0.33 S, 32.58 E	11	Mosting C	2.02 S, 8.07 W
2	Descartes	8.85 S, 15.57 E	12	Rima Bode II	12.88 N, 3.78 W
3	Hadley/Apennines	24.78 N, 2.45 E	13	Gassendi E	17.30 S, 39.38 W
4	Davy Rille	10.87 S, 6.00 W	14	Gassendi W	17.48 S, 40.23 W
5	Littrow	21.77 N, 28.97 E	15	Albulfeda [sic]	14.83 S, 14.00 E
6	Marius Hills	14.60 N, 56.57 W	16	Gaudibert A	12.02 S, 38.00 E
7	Copernicus	9.70 N, 20.30 W	17	Schroter's Valley	25.52 N, 49.93 W
8	Tycho	40.93 S, 11.25 W	18	Aristarchus	26.40 N, 44.10 W
9	Alphonsus	13.38 S, 4.30 W	19	Dionysius	2.80 N, 17.88 E
10	Hyginus	7.97 N, 6.18 E	20	South of Alexander	37.92 N, 14.08 E
			21	Rima Prinz I	28.10 N, 44.37 W

Manned Spacecraft Center (MSC), 1970. Lunar alternate missions for Apollo 13 (Mission H-2). Memorandum 70-FM55-38, 13 February 1970, FM5/Lunar Mission Analysis Branch, Manned Spacecraft Center, Houston.

NASA, 1970. *Apollo 13 prelaunch mission operation report*, Report M-932-70-13, NASA Office of Manned Space Flight, 31 March 1970.

Whitaker, E. A., 1972. Artificial lunar impact craters: four new identifications. *Apollo 16 Preliminary Science Report*, NASA SP-315, pp. 29-39 to 29-45. Washington, D. C.: NASA.



07 May 1970: Apollo Site Selection Board

ASSB met on 7 May, two days after the first meeting of a new advisory body set up by MSC to provide advice from scientists to mission planners, the Science Working Panel (SWP). SWP replaced GLEP in providing advice to ASSB, though ASSB minutes often referred to the new body as GLEP out of habit.

Following the cancellation of Apollo 13's landing, GLEP (SWP) reinforced the importance of the Fra Mauro site by recommending that Apollo 14 land at the same place. Apollo 15 would now be targeted for Davy, but flight planners had concluded that they could not land within walking distance of the old crater rim, causing serious reservations about this choice. The preference now was for sites which provided multiple sampling objectives, or different types of material, since it was now clear that the number of landings would be severely limited and another had just been lost. Apollo 14 offered important opportunities for bootstrap photography in support of future landings. The prime objective would be Descartes, but Davy was also of high interest. Censorinus could also be photographed, but was now of lesser interest as an objective.

The Davy site was of interest because its crater chain was suspected of being a string of volcanic vents which could have brought material from great depths to the surface. This interpretation is no longer considered likely.

Following the impact of fragments of Comet Shoemaker-Levy 9 on Jupiter in July 1994, many such crater chains are now thought to be caused by the impacts of fragmented asteroids or comets.

Three locations were now being considered for landing (Figure 175A): the floor of the large old crater Davy Y near one of the large pit craters, the highlands on the rim of Davy Y near the most easterly of the pit craters in the chain, and the foot of the Davy Y crater wall, the geological contact between wall and floor materials, within walking distance of the crater chain. The latter site is the one illustrated in Figure 169B. Mission planners recommended the first of the three, so the preferred target was about half way along the crater chain, roughly 8 km from the eastern rim of Davy Y. This offered a safe landing area near the crater chain, but was too far from the highlands for astronauts to reach by walking. No rover would be ready for this mission, then counted as Apollo 15. Copernicus, Marius Hills and Descartes would also be possible for Apollo 15, but SWP thought they would be better for the forthcoming J missions which would carry rovers.

Site discussions continued at MSC and among the Site Selection Subgroup of GLEP/SWP over the summer of 1970. The subgroup members met on 17 June to consider sites for Apollos 16 and 17, already aware that they might lose more landings to budget cuts. They reconsidered 14 sites: Alphonsus, Censorinus, Copernicus, Descartes, Dionysius, Flamsteed, Gassendi, Hipparchus, Hyginus, Littrow, Mösting C, Rima Bode II, Sinus Medii and the Marius Hills. They decided that Gassendi was too rough to support a landing. Also, MSC finally ruled out Copernicus and Censorinus for the same reason. The final recommendation was for Apollo 15 to go to Marius Hills, with Littrow as a backup. Descartes would be the Apollo 16 target. Only these three sites and Hadley-Apennines were still thought suitable for the remaining landings.

Apart from these considerations, SWP also continued looking at several detailed EVA plans for different sites during this period. Figure 175B is the Science Working Panel's plan for Copernicus considered in May 1970. The map shows EVAs using a rover with 10 km and 5 km ranges, and walking EVAs in the event that the rover was unavailable or damaged. Other Copernicus EVA plans are shown in Figures 168D and E. SWP's Marius Hills plan considered at a 22 June meeting is summarized in Figure 169C. Details of the EVA routes differ from previous plans (Figures 121A, 124, 136A). These new plans are more commensurate with the existing Apollo system than the extravagant scenarios described earlier.



12 September 1970: Luna 16

The Soviet Union's Luna 16 was the first successful robotic spacecraft to return lunar regolith samples to Earth, following several previous failures including Luna 15. The three sample return flights (see also Luna 20 and Luna 24) can be considered the most important scientific achievements of the Soviet lunar exploration program. The spacecraft consisted of a small return capsule on top of a main landing stage. The landing stage had a cylindrical core with four landing legs, fuel tanks, a descent engine and associated controls. It was equipped with cameras, radiation and temperature sensors, communication hardware and a drill deployed on a hinged arm for sample collection and delivery to the return capsule. The ascent stage had a small cylindrical core with a spherical re-entry capsule on top. At its base were the ascent rocket, attitude control thrusters and spherical fuel tanks. The sealed sample container was stored inside the re-entry capsule.

The 5600 kg Luna 16 was launched from Baikonur at 13:26 UT on 12 September 1970, entered a parking orbit, and was then propelled towards the Moon. After one trajectory correction on 13 September it entered a circular 111 km lunar orbit inclined 70° to the equator on 17 September. A day later the spacecraft dropped into an orbit with a low point of 15.1 km and after another slight orbit adjustment on the following day it landed on the Moon at 15:18 UT on 20 September in Mare Fecunditatis, at 0.68° S, 56.3° E (also reported incorrectly as 0.4° N, 56.1° E, which was perhaps the target), about 100 km west of Webb crater. The large descent engine shut down 20 m above the surface, and the smaller landing jets at 2 m, when the velocity was below 2.4 m/s, allowing the vehicle to drop to the surface.

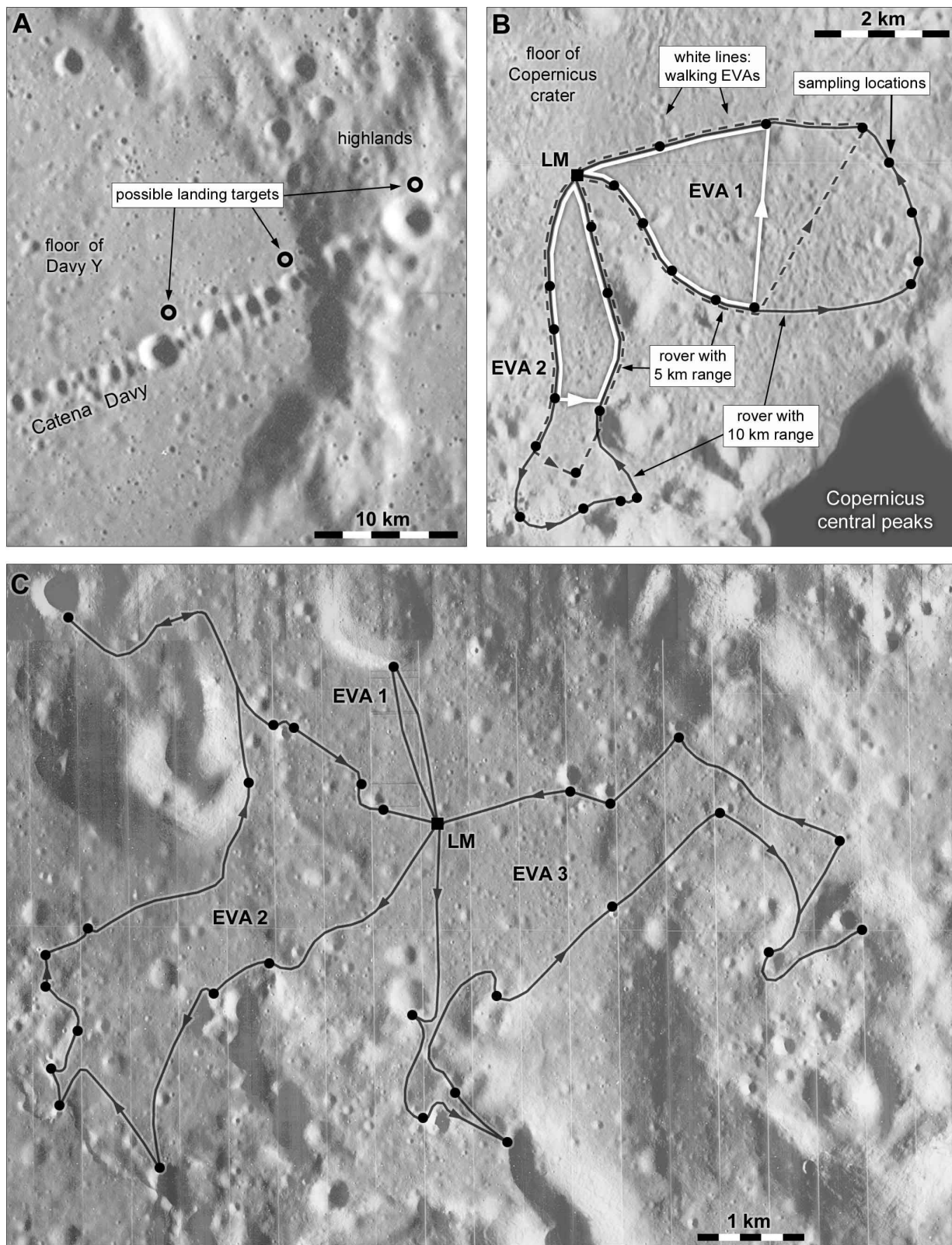


Figure 175. Future Apollo landing sites. A: Davy, showing the approximate locations of the three candidate landing sites on part of Apollo 16 Metric Camera frame AS16-M-1973. B: Copernicus EVAs on Lunar Orbiter 5 frame 152-H1. C: Marius Hills EVAs on Lunar Orbiter 5 frames 216-H3 and 217-H1. Dots represent sampling locations.

Luna 16 was equipped with twin television cameras on a forked structure which cradled the drill arm in its upright position. They were intended to help select a safe sampling location. If the area immediately in front of the drill was blocked by rocks, the arm could be rotated sideways to reach a better drilling location. Luna 16 landed about 60 hours after local sunset, and carried lamps to illuminate its sampling area, but they failed. The panoramic images transmitted to Earth were nearly featureless, but showed a few bright spots where Earthshine illuminated the terrain according to Don P. Mitchell, who had the information from camera designer Arnold S. Selivanov. They were probably of no use in drill site selection and were never published. If the original digital data could be retrieved, modern image processing techniques might reveal some useful details.

The drill was deployed, operating for seven minutes and reaching a depth of 35 cm before encountering a rock, when drilling was stopped. The sample was placed in the return capsule, and after 26.4 hours on the lunar surface the ascent stage was launched at 07:43 UT on 21 September with its payload of 101 grams of regolith.

The return flight was designed so that the small spacecraft, leaving the Moon's gravitational influence, was orbiting Earth with less than the Moon's orbital velocity, causing it to fall towards Earth. This arrangement mandated a launch from low latitudes at about 60° E, which restricted the landing site locations of all the Soviet sample return missions. The return capsule coasted back to Earth without any trajectory correction and landed in Soviet territory, 80 km SE of the city of Dzhezkazgan, Kazakhstan, at 03:26 UT on 24 September. The landing stage operated for some time after ascent stage liftoff, transmitting temperature and radiation data.

Figure 176A shows the landing sites of Luna 16 and Apollo 11, and the approximate Luna 15 impact site plotted on the Defense Mapping Agency's *NASA Lunar Earthside Chart (LMP-1)*, original scale 1:5 million, 3rd edition, May 1976. The pre-launch target point for Luna 16 is not known, but it was probably close to the actual landing site, as noted above. This area was later named Sinus Successus (Bay of Success). The area of northeastern Mare Fecunditatis, with the location of the Luna 16 landing site among wrinkle ridges northwest of Langrenus crater, is depicted in Figure 176B. The base map is a detail of *Karta Luny, Ekvatorialnaya Zoni, Sheet 7 (More Pen')*, original scale 1:1 million, Sternberg State Astronomical Institute, Moscow, 1968. The mare surface here probably contains a small amount of material ejected from Langrenus. Figure 176C shows the best LRO image of the lander, and Figure 177 locates the site in a sequence of nested images.

The Luna 16 regolith sample is small compared with Apollo sample collections, but it is important as the only material from this mare region. It consists of basalts containing more aluminium than most mare basalt samples returned to Earth by other missions (Vinogradov, 1974), emphasizing that the maria are not chemically identical. It was dated as 3.40 billion years old (Wilhelms 1987), intermediate in age between Apollo 11 and 12 samples.

Vinogradov, A. P., 1974. *Lunnyĭ grunt iz Morya Izobiliya [Lunar Soil from the Sea of Fertility]*. Moscow: Nauka press. Translated as NASA-TT-F-15881. https://archive.org/details/nasa_techdoc_19750003742

Wilhelms, D. E., 1987. *Geologic history of the Moon*. USGS Professional Paper 1348. Washington, D. C.: U. S. Government Printing Office.



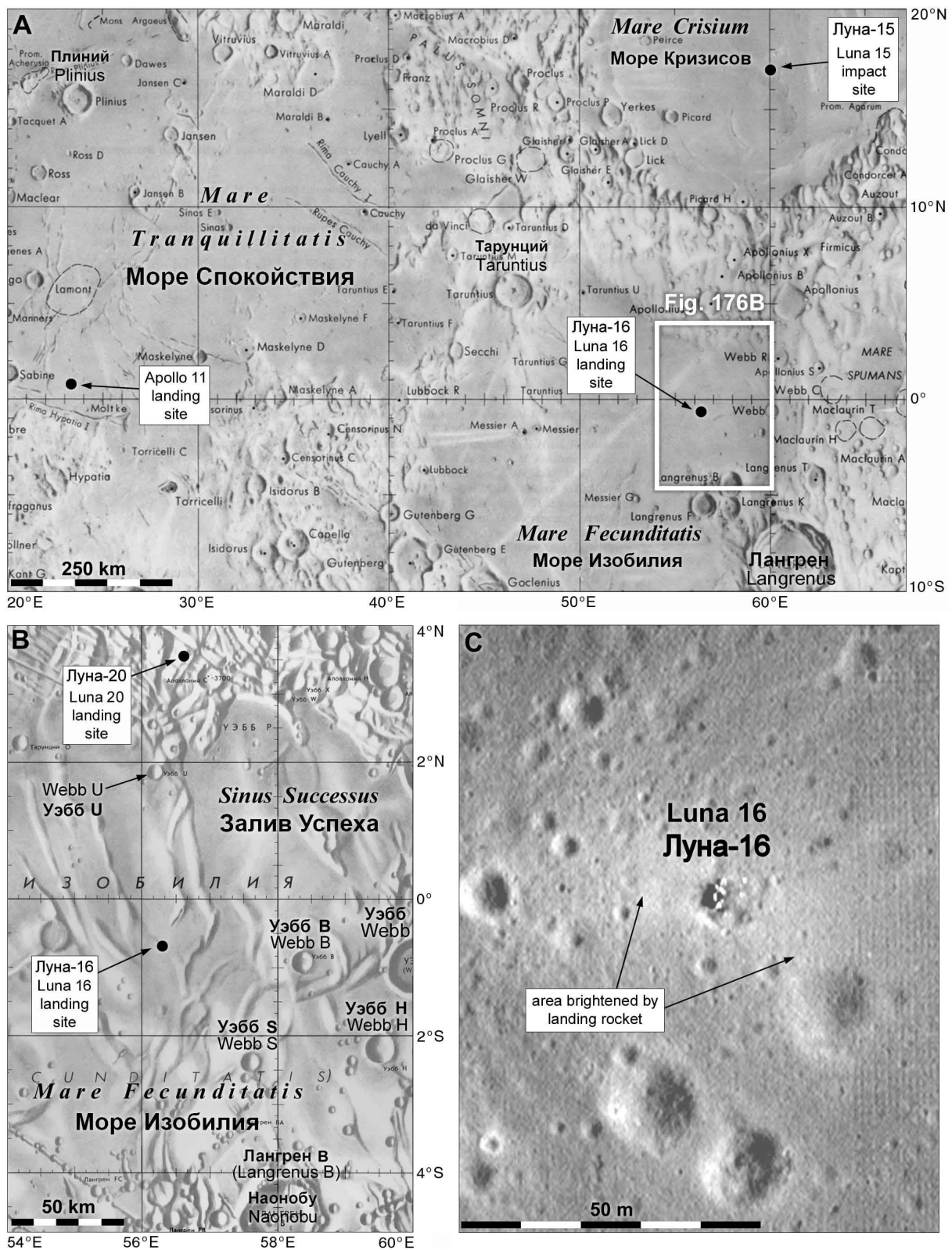


Figure 176: Luna 16 landing area. A: context of the landing region. B: Luna 16 landing site. The base maps are identified in the text. C: Luna 16 in LROC image M174909036R.

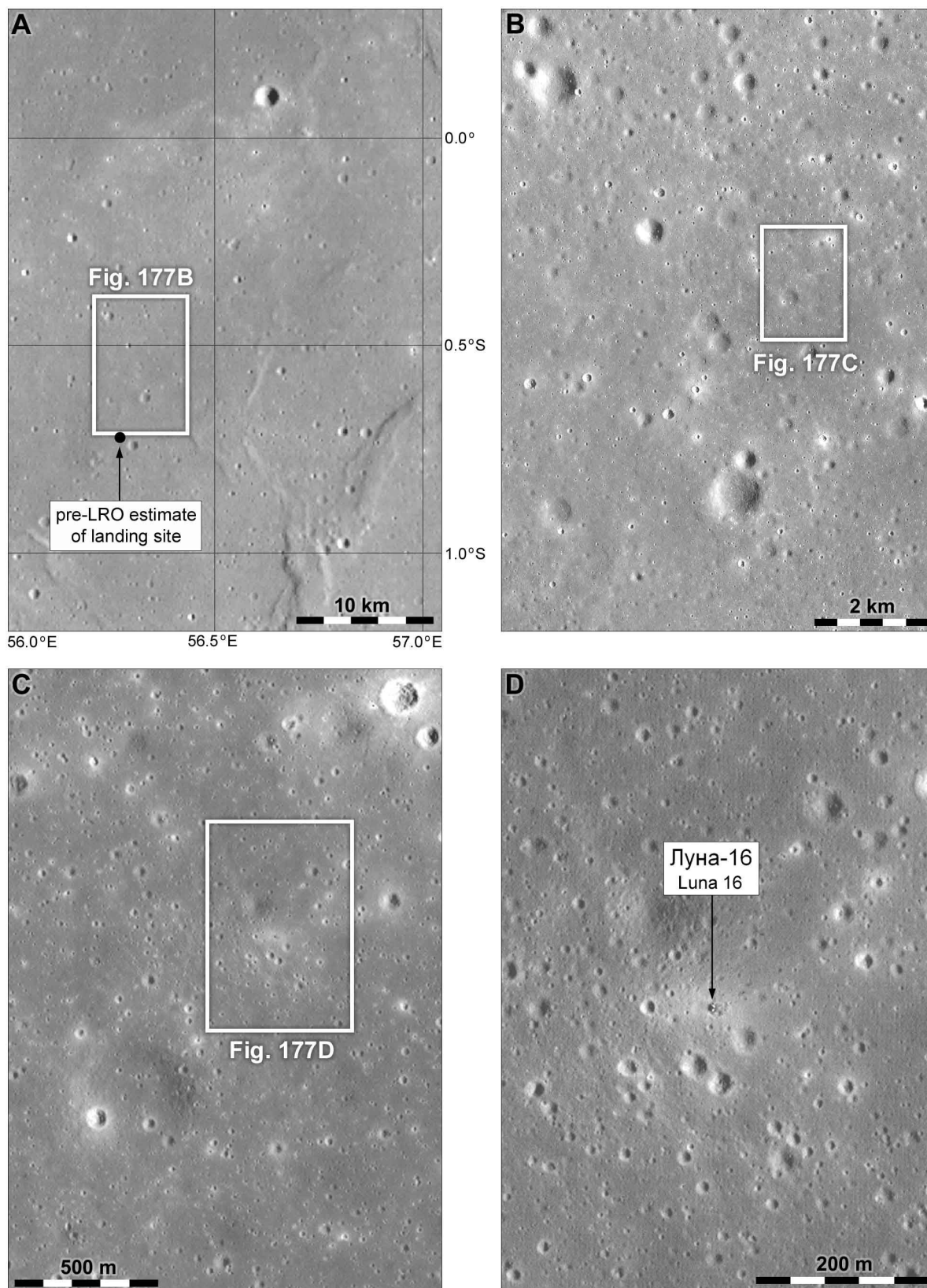


Figure 177: Luna 16 landing site. A: LROC Wide Angle mosaic. B, C, D: LROC image M159582808L.

24 September 1970: Apollo Site Selection Board

After Congress cut NASA's budget for Fiscal Year 1971, NASA was forced to cancel two more lunar landings. The cuts were announced on 2 September 1970. Rather than cutting two of the four more capable J missions, NASA opted to cut the last H mission and the last J mission (Apollos 15 and 19 according to the numbering of Table 54).

MSC sought advice on the remaining landing sites from independent groups of scientists. The geochemists suggested sites to the Board for missions 15 to 18, before it became apparent that there would be no Apollo 18. The various groups considered Littrow, Censorinus, Marius Hills, Tycho, Davy, Descartes, Copernicus, Hadley and Tsiolkovskiy, on the far side. Their recommendations are given in Table 56. Exploration advocates sometimes referred to as the 'lunar mafia' supported Tsiolkovskiy for Apollo 18 as a dramatic end to Apollo, and when the last landing was cancelled the suggestion resurfaced for Apollo 17. Astronaut/geologist Harrison Schmitt himself proposed Tsiolkovskiy as his mission target, arguing that it would constitute a worthy end to the Apollo Program.

A significant problem was that a farside landing would require a communications relay satellite. A flight spare of a military communication satellite might be adapted for use in a halo orbit around the Earth-Moon L2 Lagrangian point over the lunar farside, but the funding could not be found. The Board was not sure that a farside landing was even possible with Apollo hardware and procedures, but NASA's Goddard Space Flight Center (GSFC) and MSC studied the spacecraft modifications and hardware it might require. In a presentation at MSC (Lunar Backside Landing for Apollo 17, presentation materials, 2 September 1971) they described a mission with three traverses near the edge of the dark mare deposit on the crater floor just north of the central peak (Figure 178A, B), giving access to both farside highlands material and the relatively young mare. The communication relay satellite in its halo orbit at L2, 64500 kilometers beyond the Moon, would provide a continuous radio link between astronauts at Tsiolkovskiy and Mission Control on Earth. This strategy was eventually used by China for its Chang'e 4 mission launched in 2018.

A Defense communication satellite project was already under way with a plan for six satellites, two of which were to be stored for later use as spares, and these might be repurposed for Apollo 17. However, the relay satellite, or pair of satellites to provide a backup, would not be the only costs associated with a Tsiolkovskiy mission. The GSFC/MSFC study team considered modifications to ground systems, the ALSEP (which for prolonged use would require operation of the relay for several years after the mission), the LRV and the LM, all of which would have to track the relay satellite rather than the essentially static Earth. These changes might cost up to \$77 million, depending on the type of relay satellites selected. If the Tsiolkovskiy mission was approved by October 1971 the relay satellites should be ready for launch by September 1972.

Table 56. Science site priorities for the remaining landings.

Mission	Geology group recommendation		Geochemistry group recommendation		Geophysics Group recommendation		MSC recommendation	
	preferred	second choice	preferred	second choice	preferred	second choice	preferred	second choice
15	Tycho	Descartes	Descartes	Copernicus Hadley	Hadley		Hadley	Copernicus
16	Davy		Copernicus	Descartes	Descartes		Descartes	
17	Marius		Davy	Hadley Marius	Davy	Marius	Marius or Copernicus or new site	

When these recommendations came to ASSB, Copernicus, Davy, Descartes and Tycho were all considered, but Hadley and the Marius Hills were favoured. Both seemed acceptable but Hadley was preferred by the astronauts themselves, so the Board eventually recommended Hadley for a flight in mid-1971. It offered dramatic mountains, a sinuous rille and another mare area, and its relatively high latitude was ideal for the growing array of ALSEP instruments, including another laser retroreflector. Tycho was once again dropped for being too difficult to reach.

Looking further ahead, the Board preferred Descartes for Apollo 16, with a launch early in 1972. The Apollo 17 site was not fixed at this time. Marius Hills and Copernicus were good candidates, but a highland site was strongly desired and the hope remained that a new candidate would be found in orbital photography from Apollo 14 or 15.

Once Hadley was accepted as the target for Apollo 15 there were still several candidates for the best landing site within that broad region. Figure 178C shows five potential landing sites considered by the Science Working Panel at a meeting on 20 October. Sites between the rille and the mountains were preferred to provide access to both, and Site 3 required a very steep descent after clearing a nearby peak, so sites 1 and 5 were preferred. The minutes of the meeting include EVA routes for landings at site 1, the site eventually chosen, and site 5 at the south end of the rille (Figures 178C and D respectively). Site 1 was eventually selected because it offered the best walking EVA options. It lay outside the limits of the high resolution Lunar Orbiter 5 photography, but growing experience suggested that extrapolation from the medium resolution images would be acceptable.

An example of the studies which lay behind these choices is Benjamin and Head (1970), which considered site 5 under various mission scenarios. Apollo 15 could have been an H mission resembling Apollo 12 with two walking EVAs, or a J mission with three EVAs and a rover to allow more extensive operations. EVA plans were developed for walking missions assuming PLSS operating times of 4.5, 6 or 7 hours (Figure 179A-F) and for a rover mission (Figure 179G). Longer operations allowed access to more sites.

Benjamin, P. and Head, J. W., 1970. Preliminary analysis of traverse capabilities for a possible Apollo 15 mission to Hadley-Apennines. Cases 320 and 340. Bellcomm memorandum B70 07094, 27 July 1970. NASA-CR-109975.



20 October 1970: Zond 8

The 5375 kg Zond 8 was the last of the circum-lunar flights by this precursor of Soviet human flights to the Moon. It was launched from Baikonur at 19:56 UT on 20 October 1971, placed in a parking orbit and then put on its translunar trajectory. After this final flight test of the Soyuz lunar hardware, the program was cancelled in favour of Earth-orbit space station missions. Zond 8's cameras photographed Earth on 21 October 21 from 65,000 km, and television images of Earth were transmitted during the three day flight to the Moon.

Zond 8 looped around the Moon on 24 October at an altitude of 1100 km, taking full disk images and a long strip of very high resolution images across the farside, beginning with earthset and ending at the terminator near Aitken crater. Zond 8 returned to Earth and splashed down in the Indian Ocean on 27 October. A guidance system failure caused a hard re-entry, which would not have been survived by a crew.

Figure 173 shows the farside image coverage obtained from all Zond and Apollo missions. Zond 8 image coverage is shown with a black outline. Coverage from Zonds 6 and 7 is shown with gray outlines, and the combined coverage of all Apollo missions is shown with a subdued white outline. Apollo low resolution coverage and earthshine images in the Orientale area at far right are not shown. This map illustrates the highly complementary nature of the various data sets. Zond 8 photography is of excellent resolution and quality. Where it overlaps Apollo photography, its reversed lighting reveals areas otherwise lost in shadow. Shaded relief and geomorphological maps of the area covered by Zond 8 images were compiled at MIIGAiK in Moscow.

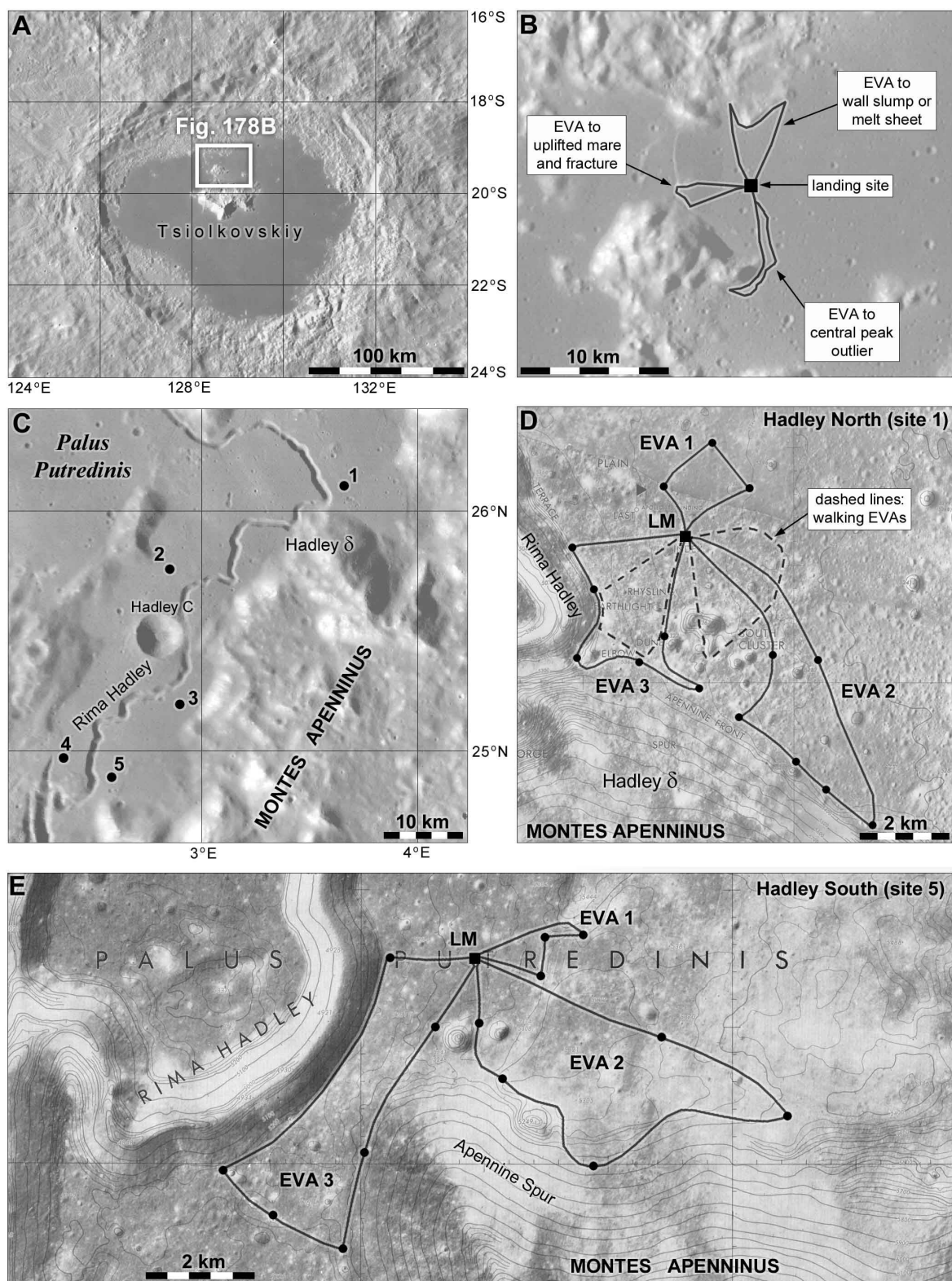


Figure 178. Late Apollo EVA plans. A, B: Tsiolkovskiy plan for the last Apollo mission. C: Five landing sites in the Hadley region. C: Hadley North (site 1) EVA plan. D: Hadley South (site 5) EVA plan. C and D are drawn on parts of DMA NASA Lunar Topophotomaps 41B4S1(50) (*Rima Hadley North*) and 41B4S3(50) (*Rima Hadley South*), original scales 1:50000, 1st editions November 1974 and May 1975, respectively.

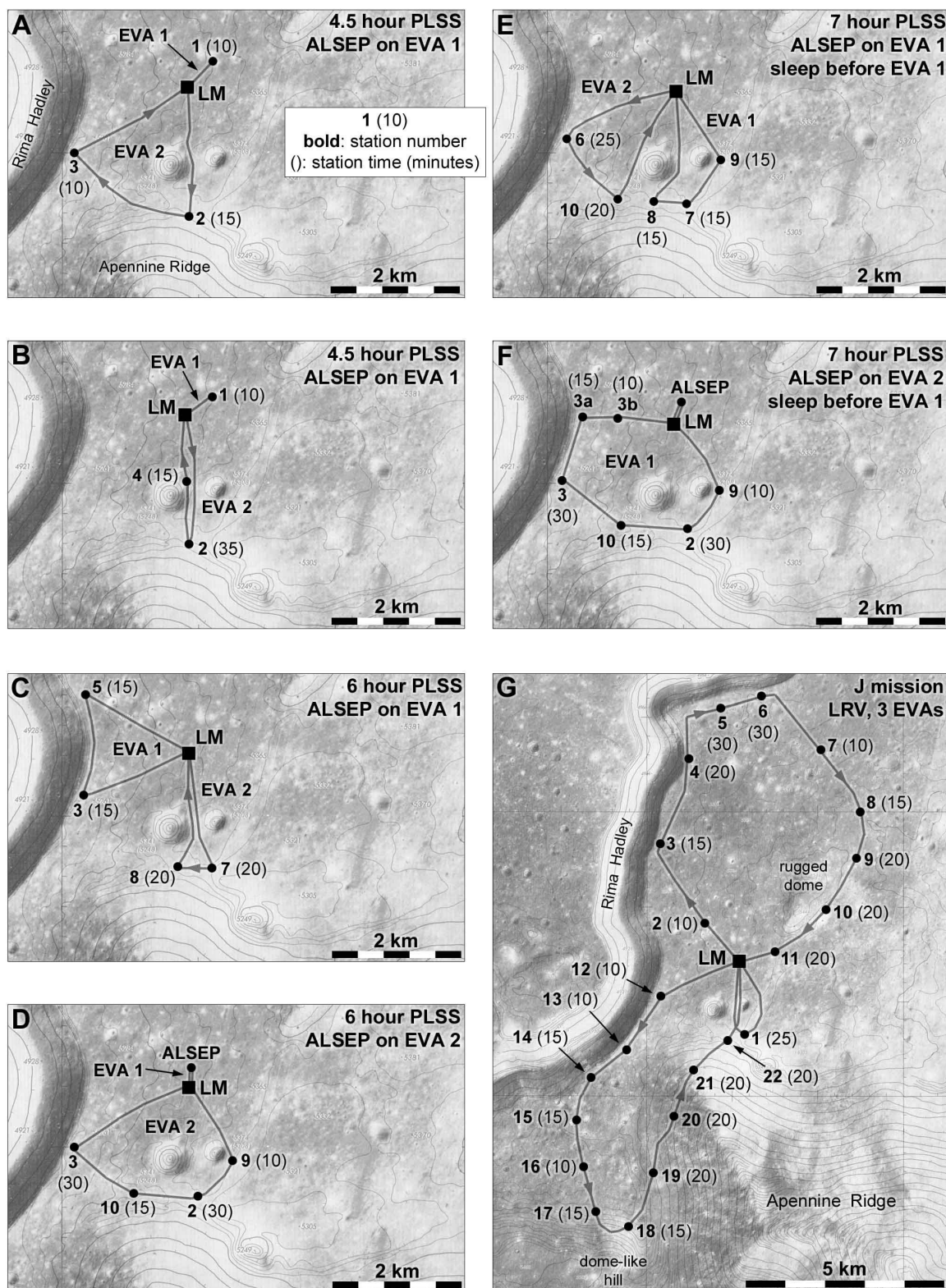


Figure 179. Late Apollo EVA plans, continued. Hadley South studies from Benjamin and Head (1970). These plans are described in the accompanying text. The base map for A-F is DMA NASA Lunar Topophotomap 41B4S2(50) (*Rima Hadley Central*), the base for G is a composite of that and 41B4S3(50) (*Rima Hadley South*), original scales 1:50000, 1st editions April and May 1975, respectively.

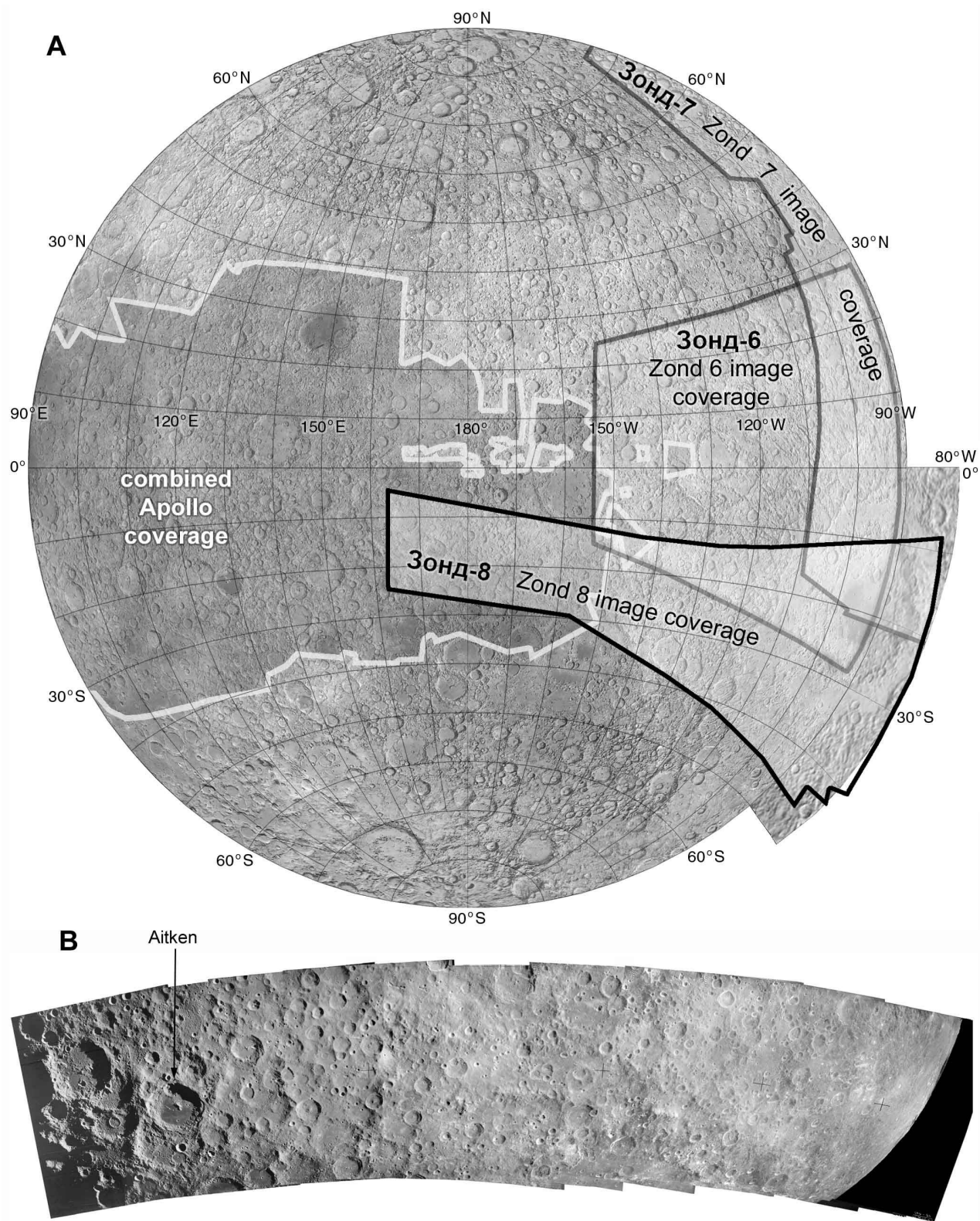


Figure 180. Zond 8 images. A: Zond 8 and other farside image coverage. B: Zond 8 image mosaic compiled by P. Stooke. It runs from the terminator to the limb across the northern edge of the South Pole-Aitken basin.

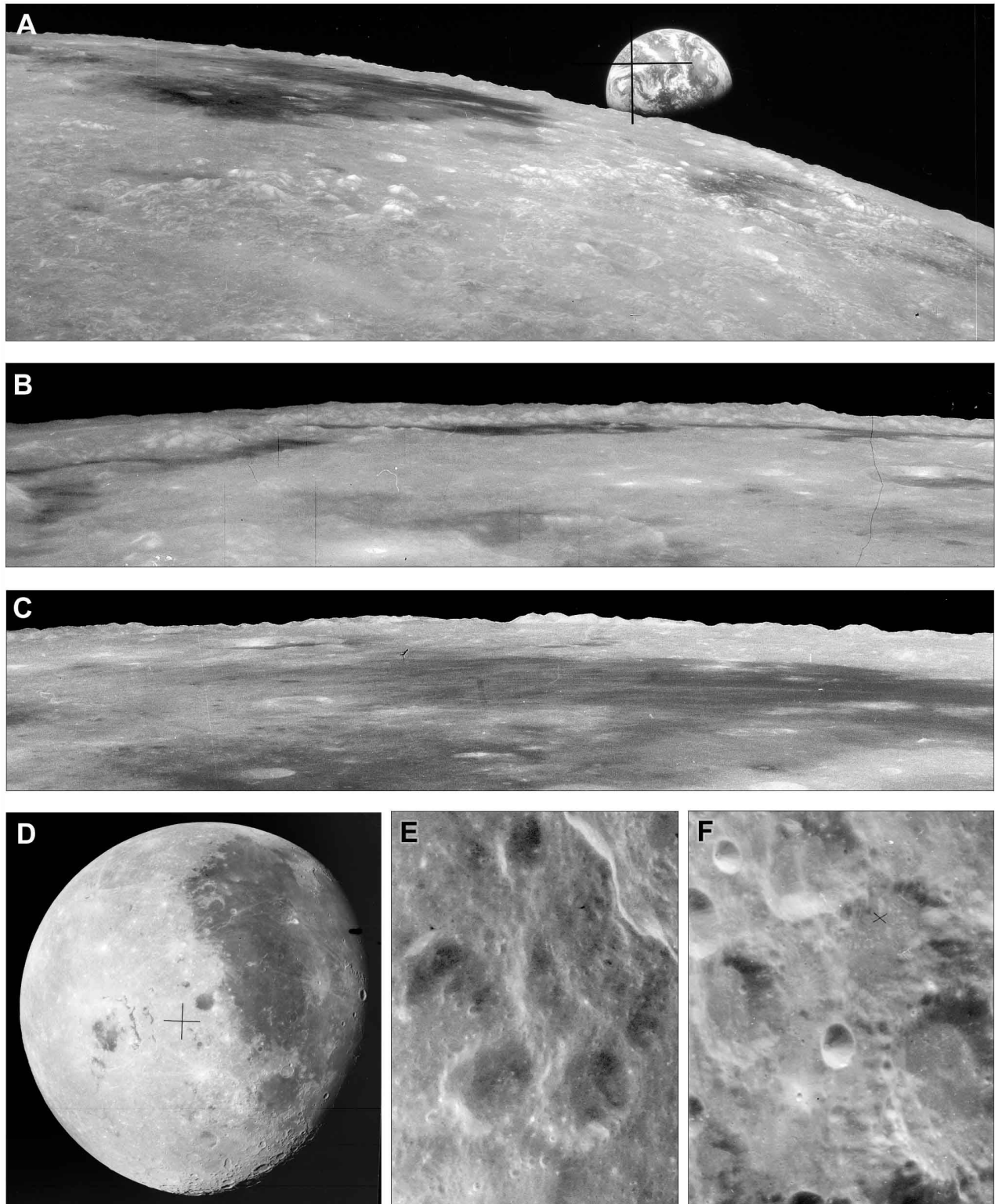


Figure 181. Zond 8 images. A: earthset over Mare Orientale. B, C: two views of Montes Cordillera on the lunar horizon. D: global view from 9600 km altitude. E: the Ranger 4 impact area. F: Craters with smooth plains fill.

Figure 181 shows representative Zond 8 images. Figure 181A shows Earth setting over Mare Orientale as Zond 8 moved behind the Moon. Figures 181B and 181C show different parts of the Montes Cordillera on the limb. Figure 181C includes the dark lavas of Mare Orientale, and small dark spots where that lava has been excavated from beneath later ejecta by recent small impacts. Figure 181D is a high altitude view showing Mare Orientale at left and Oceanus Procellarum at right. Figure 181E is the Ranger 4 impact area, not seen more clearly until the Clementine mission 24 years later. Figure 181F shows craters with smooth plains fill, possibly Orientale ejecta, on the northern rim of Apollo basin (30° S, 140° W), in an area not photographed at high resolution by previous missions. The largest crater is Kleymenov. F: All Zond images were provided courtesy of MIIGAiK, T. Nyrtsova and K. Shingareva, who provided high resolution scans from the original negatives.



10 November 1970: Luna 17/Lunokhod 1

The Soviet Union's Luna 17 carried the 750 kg Lunokhod 1 rover which could be remotely controlled by a five person crew at a communication centre outside Moscow. This was the first remotely controlled rover mission ever carried out on another world. The spacecraft was launched from Baikonur at 14:44 UT on 10 November 1971, placed in a parking orbit, then sent to the Moon. It entered lunar orbit on 15 November, initially a circular orbit at 90 km altitude with an inclination of 141°. Later its low point was dropped to 20 km, and it landed on 17 November at 03:47 UT at a position usually stated at the time as 38.28° N, 35.00° W in northwestern Mare Imbrium. The lander was eventually located in LRO images at 38.238° N, 34.997° W.

The landing spacecraft, Luna 17, was similar in design to Luna 16, with four landing legs and a body dominated by the fuel tanks for the landing rocket system. The lander had dual ramps by which Lunokhod 1 could be driven down to the surface, so if one exit was blocked by a rock or crater the other could be used instead. Lunokhod 1 consisted of a near-cylindrical pressurised compartment, tapered slightly towards the base, on eight independently powered wheels. Internal temperatures were maintained at night by a radioisotope heater. On top were a conical omnidirectional antenna and a high gain helical antenna. Two television cameras mounted at the front provided information to drivers on Earth. Two panoramic cameras were mounted on each side of the body, one facing outwards and one facing downwards, both providing 180° views from the forward to backward directions.

The body also supported deployable experiments to contact the lunar regolith for density and mechanical property tests. An x-ray spectrometer for soil composition measurements, a regolith radioactivity detector, an instrument for solar and cosmic x-ray observations, cosmic-ray detectors, and a French laser retroreflector were also operated. Lunokhod was powered by batteries charged by solar cells mounted on the underside of a large convex folding lid, which was closed at night to help insulate the interior and opened during the day to provide power.

Lunokhod rolled off the east-facing ramp of its lander at 06:28 UT on 17 November. It was intended to operate for three lunar days but survived for eleven lunar days (322 Earth days). Operations officially ended on October 4, 1971, by which time it had travelled 10.5 km and had obtained more than 20,000 single pictures (to assist with driving operations) and over 200 panoramas. It conducted about 500 lunar regolith tests by pressing a probe into the ground, observed wheel tracks to estimate regolith mechanical properties, and made chemical composition measurements by means of an X-ray spectrometer at 25 locations. The Lunokhods were originally conceived as vehicles which would survey and prepare sites for human landings, but they became effective explorers on their own.

Luna 17 landed about 60 km southwest of Promontorium Heraclides, the southern end of the Montes Jura surrounding Sinus Iridum (Figures 175, 176). Tracking suggested the lander touched down at 38.28° N, 35.00° W. Contemporary laser reflections are discussed below, but the location they gave was too uncertain to target the rover from Earth in the 21st Century using lasers with smaller footprints on the Moon. Stooke (2005, 2007) suggested a location at 38.26° N, 35.19° W (38.22° N, 35.20° W in modern coordinates using Quickmap) by comparing a Soviet-era map of craters along the traverse (Vinogradov, 1971a; 1971b) with craters seen in the best pre-LRO image,

which was an oblique Hasselblad image taken during the Apollo 15 mission. The low resolution of the image and problems with the map prevented an accurate match, resulting in a suggested location about 6 km west of the true site (Figure 182B). The exact location was identified in LRO images (Wagner *et al.*, 2017) with coordinates 38.238° N, 34.997° W.

Figure 182 shows the region in which Luna 17 landed. This was the most northerly landing site on the Moon during the missions of the Luna and Apollo period, about 1200 km north of Surveyor 1 and Apollo 12. Only in 2014 did another lander, China's Chang'E 3, reach a higher latitude. Figures 182B, 182C and 183 locate the lander and parked rover precisely in a set of nested maps. The landing site is several kilometres east of a prominent north-south trending wrinkle ridge in the plains, part of which was just visible from the landing site and was interpreted as a crater rim, contributing to Stooke's 2007 confusion over the location.

Lunokhod 1 began by driving south from its landing site (Figure 185). After two lunar days it stopped at its southernmost point in a 150 m diameter crater (Figure 186). On the third day it returned to the lander, moving faster as its drivers gained experience. On the fourth day it moved towards the north (Figure 187), spending three lunar days exploring the largest craters it encountered. In its final months of activity Lunokhod 1 was driven further north, generally in the direction of the hills seen on the horizon. It was navigated around a cluster of craters during the summer of 1971 (Figure 191). In its final month it moved only a short distance as it was wearing out. Operations ceased when the internal gas pressure dropped and the radioactive heat source was no longer able to keep the equipment warm during the eleventh lunar night. The vehicle had been parked in a position which allowed its laser retroreflector to be used for later ranging studies.

The route of Lunokhod 1 is mapped in Figures 184-191. Figure 184 serves as an index for the next seven maps. The route is mapped precisely over the rover tracks visible in LRO images. Where tracks are difficult to identify in the clearest image the interpretation is based on multiple images and image composites. Annotations are based on multiple sources of data including the original Soviet source (Vinogradov 1971a; 1971b) and new mapping with LRO images and modern mapping methods by Karachevtseva *et al.* (2013). The 100 m grid overlay shows distances measured from the landing site. Areas labelled as Plans 1 to 7 are mapped in more detail in Figures 192 and 193.

Details of the mission activities in the text are a composite of information from Vinogradov (1971a; 1971b), Ulivi and Harland (2004), Karachevtseva *et al.* (2013), Gallentyne and Ferdowski (2016), Basilevsky *et al.* (2021), and from interpretation of the LRO images and maps.

Lunokhod 1 was not normally driven when the sun was low in the sky because long shadows made safe driving difficult, or when the sun was too high to show relief clearly. The pattern of drives indicated by dates on the maps includes a long break during each lunar night and a shorter stop around local noon on most days.

The first images were transmitted while the rover was still on the lander, two hours after landing, showing that there were no obstacles to interfere with ramp deployment. Ramps were deployed in both east-facing and west-facing directions in case one path was blocked by a rock or a deep crater. Either direction would have been safe, but the rover was driven off the east-facing ramp and then out over the lunar surface, stopping after about 20 m to image the lander and charge the batteries. The X-ray spectrometer was used at this location for the first time to measure the composition of the surface. On the next day Lunokhod was driven about 90 m to the southeast, stopping to map a small crater with stereoscopic images (Plan 1, Figure 192B) and to measure composition again.

The drive on the third Earth day of operations was about 100 m, climbing up a small hill. Plan 2 (Figure 192C) was made here, and the rover operators discovered that the brakes had failed in the 'on' position, which slowed the rover in all subsequent driving but did not halt its progress. The rover parked here after 232 m of driving (Table 56) for its first lunar night, closing its lid to help keep the interior warm. The night lasted from 22 November to 10 December. On 5 and 6 December 1970 two laser shots were made from Pic du Midi Observatory, producing only very weak returns. More laser details are given below.

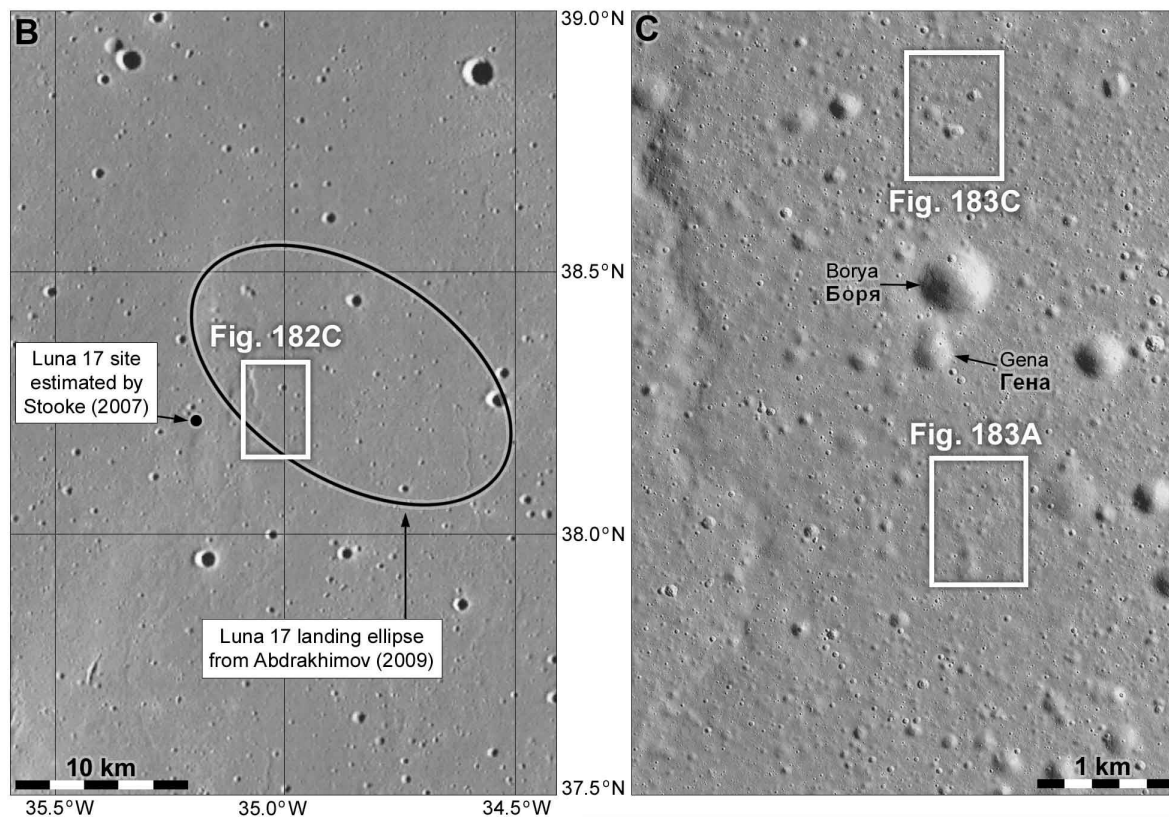
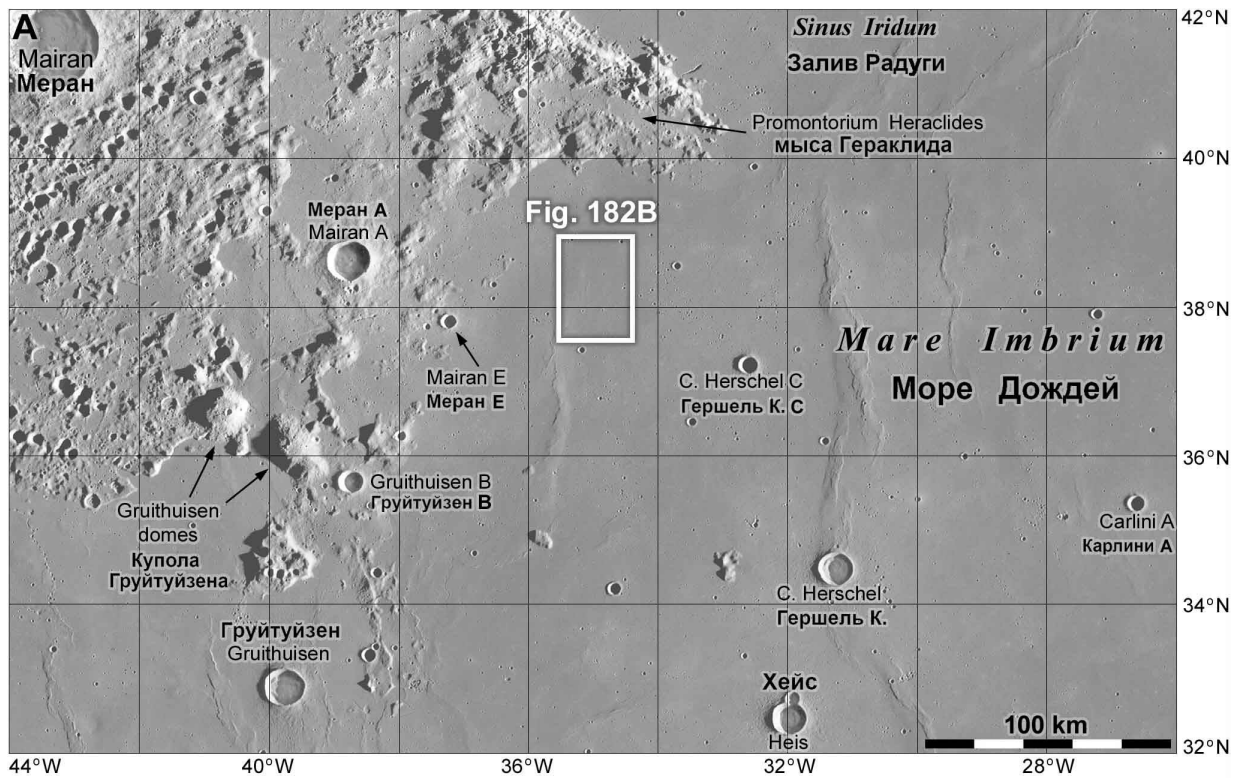


Figure 182: Luna 17 landing area. A: the broader landing region. B: The landing area. A and B are LROC Wide Angle mosaics. C: the landing site in LROC image M150749234.

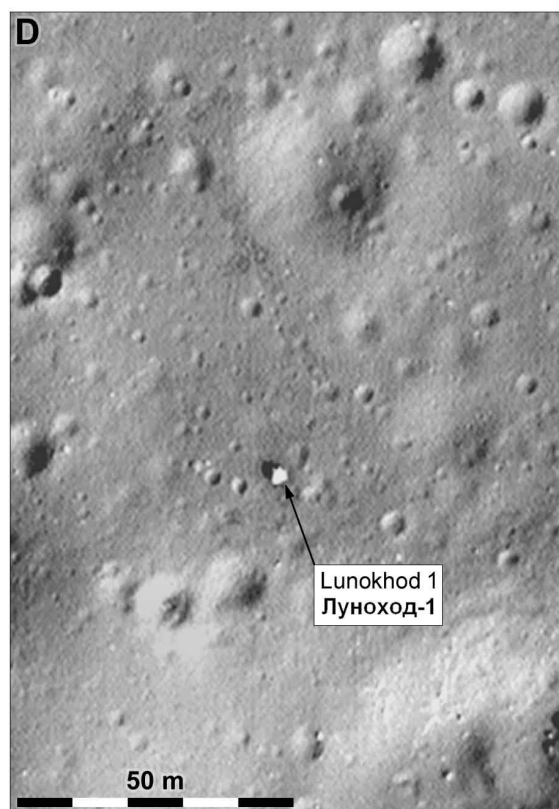
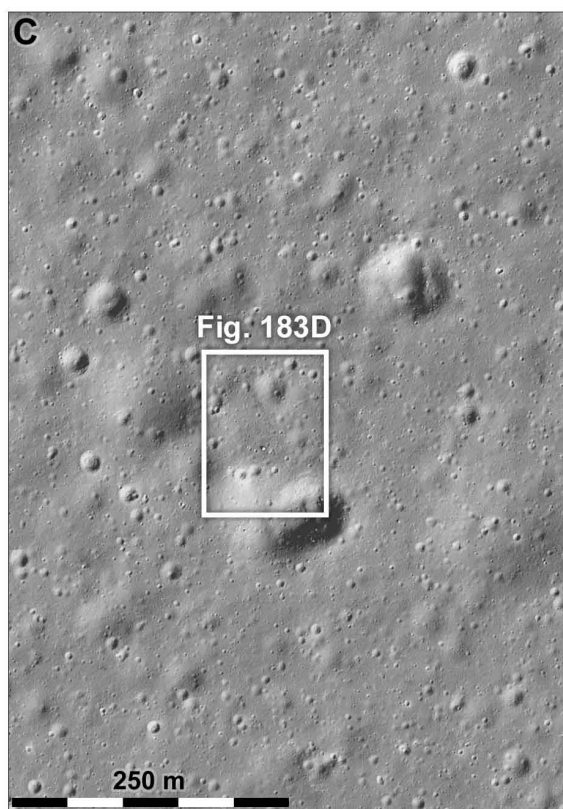
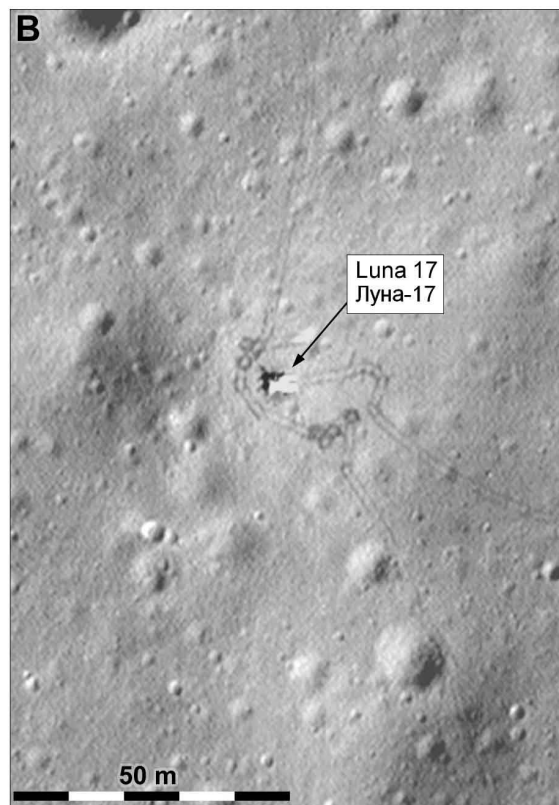
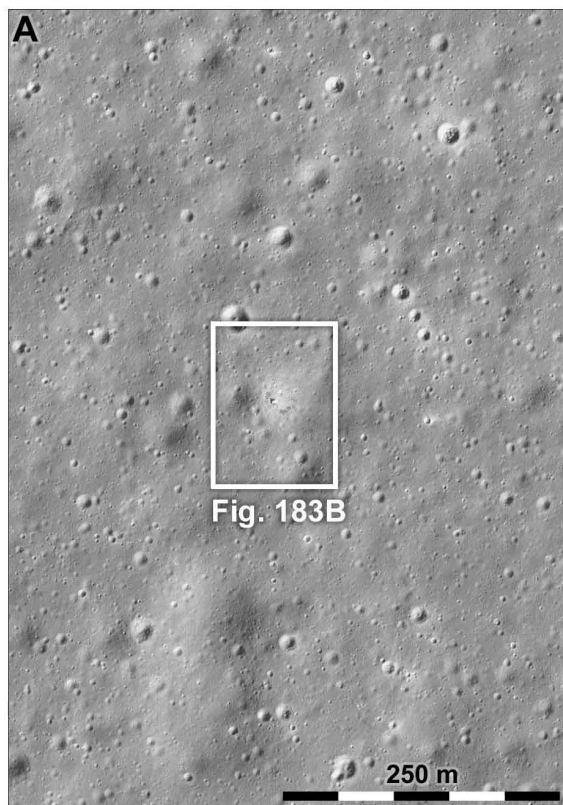


Figure 183: The locations of Luna 17 and Lunokhod 1. All images are parts of LRO image M175502049.

The second lunar day began with a drive to the south on 11 December. Hills at the western end of Promontorium Heraclides (Figure 196) became visible in the distance over the next days as the elevation of the ground increased. On 12-13 December Lunokhod 1 observed a solar flare which had been detected two days earlier by Venera 7 during its approach to Venus, and by Intercosmos 4 in low Earth orbit. It was strong enough to have injured cosmonauts if any had been on the lunar surface. Luckily this situation never arose during Apollo missions, but crews did consider how they might protect themselves from flares using equipment for shielding. Intercosmos 4 had detected another flare the day before Luna 17 landed. Lunokhod 1 parked from 13 to 17 December for the lunar noon period when a lack of shadows made driving difficult, but stereoscopic images allowed the site to be mapped as Plan 3 (Figure 193A).

After southward driving resumed, the plan 4 area (Figure 193B) was mapped on 20 December. On the next day the rover drove into a small crater on the eastern rim of Nikolya crater, backed out and bypassed it on the east side. Then it drove into Vasya crater and spent the second lunar night on its floor (Figure 185). Lunokhod 1 was parked from 22 December 1970 to 9 January 1971 with sunset on 23 December and sunrise on 7 January. Then, after maneuvering around the crater floor, it drove out to the north again and made a rapid drive back to the lander. This served to test navigation on the lunar surface and to extend driving experience. There was some tension between engineers who wished to test the limits of robotic operations and scientists who wanted to stop and study features.

Lunokhod stopped for photography 100 m north of its night parking spot on 11 January (Figure 186) and then drove quickly 500 m north to its next photo stop. Next it turned west to approach its southward tracks, but stopped only about 30 m from them on 12 January and moved northeast again. This drive on 12 February was the longest day's drive of the mission, about 850 m. From 13 to 16 January it waited out the lunar noon, measuring regolith composition during the stop. On 18 January it again approached its old tracks, meeting them at a point named First Lunar Crossroad on Russian maps (Figure 185). It followed them north for 50 m and then turned northwest to reach the lander more directly, reaching it on 20 January. After photographing the lander from several positions it parked for its third lunar night just northwest of Luna 17 (Figures 187, 192).

The Sun rose on 4 February and the rover recharged for three Earth days before leaving on 7 February. 150 m north of its night resting spot it was driven into a crater, but stopped and backed out before driving around the obstacle, a common experience when driving rapidly. Later that day the drivers stopped for a day to measure composition and map the Plan 5 area (Figure 193C). They skirted Igor crater on its eastern side and stopped northeast of it around lunar noon, where more composition measurements and data for Plan 6 were collected (Figure 193D). Here, on 10 February, the rover experienced a solar eclipse (a total lunar eclipse as seen from Earth). It parked 300 m further north from 11 to 16 February, around lunar noon. Lunar eclipses can only happen at full moon, which would be local noon on the Moon's prime meridian, but at this location noon came a few days after the eclipse.

Lunokhod was driven 75 m west after the noon break (Figure 181), and then to the rim of Gena crater and northwards along it, where it stopped on the rim of a small crater on 18 February. It backtracked out of this rough area to stop for the night in a flat region to the southeast, where it would be better illuminated by the rising Sun. It stopped on 19 February 1971 and resumed operations on 8 March after its fourth lunar night. 8 March is International Women's Day, a holiday in the Soviet Union, and it seemed fitting to commemorate it on the Moon. Nothing was done on the day, but tracks made during the previous lunar day included a 'figure 8' made by two adjacent turns in place (inset, Figure 188) and this was promoted as a memorial of the date. It is not clear exactly where this is along the traverse, but Figure 188 indicates possible locations. Stooke had promoted the 18 February location in social media posts in 2025 but that is probably too late in the day.

Local depressions, including one on the north side of Gena, and the raised rim of Borya crater, perhaps suggested to the mission team that the area to the west was a 500 m wide very subdued crater, and the rover was now driven counterclockwise around it. The circumnavigation began on 9 March with a drive to the rim of Borya, northwest of the fourth night position. On 12 March Lunokhod 1 was driven to the southwest through a rocky crater, and then west. The rover drove into another crater 200 m further west but had to back out of this one and turn south to avoid it (Figure 189). Large blocks were seen around a very fresh, bright-rayed crater just to its west. Then the rover turned to the southwest, spending the noon period as far west as it would ever travel, 850 m west and 1000 m north of Luna 17. Just before that it had again driven into a small crater and had to back out. On 19 March it turned east again, slowed briefly as it drove obliquely down the south wall of Vitya crater and maneuvered several times to climb back out. The much shallower Kostya crater presented no difficulty as it was crossed (Figure 189).

Lunokhod 1 was directed north again just after passing Kostya and stopped for its fifth night just south of Gena crater. The Sun rose on 5 April 1971 and work resumed two Earth days later. The rover now drove straight down into Gena, reaching its lowest elevation on the traverse (Karachevtseva *et al.*, 2013) on 8 April (Figure 188). On 9 April, 280 m north of the lowest point, the rover reached the highest point it would encounter, 26 m higher than the lowest point. Nearby it encountered its old tracks from 9 March and stopped for an analysis of the regolith and to take panoramic images. On the next day it drove down into Borya crater, among very large rocks and steep slopes with loose regolith. Extracting the rover proved difficult, but after much maneuvering and with the application of maximum power to the wheels Lunokhod 1 was eventually freed, returning to the rim of Borya just north of the highest elevation point visited only a few days earlier. Its batteries had been almost exhausted.

Here the rover rested and recharged for several days, remaining in the same place for the sixth lunar night (Figure 188). The seventh lunar day began on 5 May but Lunokhod 1 spent more time recharging and resumed work only on 10 May. Between this and the next sunset on 20 May the rover drove only about 250 m, investigating the ejecta of Borya and collecting data for Plan 7, its last detailed topographic map (Figure 193E). The batteries were fully charged again and Lunokhod 1 was driven past Valera crater and further north on 9 June. The mission team now hoped to drive far enough to get a better view of the hills of western Promontorium Heraclides, 60 km to the north, which had been glimpsed during the second lunar day. That viewpoint was further south but the terrain was at a higher elevation.

Around lunar noon in mid-June Lunokhod 1 was driven into Kolya crater, and made chemical measurements and took pictures on 14 June. After entering and backing out of two small craters it managed to climb out of Kolya, heading west, and turned northwest into a flat region between several craters. On 17 June it reached its northernmost point, 2.48 km north of Luna 17, and on 18 June it stopped for its eighth lunar night, having driven over 1500 m during its eighth day. It never achieved long drives again after this as problems began to appear. On the ninth lunar day Lunokhod 1 covered just less than 200 m, stopping on 17 July only about 80 m from its previous night's stop. The tenth day began on 3 August 1971 and ended on 14 August after only 150 m of driving.

Apollo 15 was in lunar orbit as Lunokhod 1's tenth lunar day started. Some reports (e.g. Harvey, 1988; Huntress and Marov, 2011) have suggested that a sun glint from Luna 17 or Lunokhod 1 was seen by the orbiting astronauts. The flight transcripts do not indicate this, and the story may be based on a misunderstanding of the fact that the crew looked for and took images of the landing area (e.g. AS15-93-12705, AS15-93-12714).

The eleventh lunar day began on or about 2 September 1971 and the rover was driven about 100 m, though its systems were wearing out. The Soviet map (Vinogradov, 1971a, 1971b) indicates that a panorama and a final X-ray analysis of the regolith were made on 14 September, and on 15 September Lunokhod 1 was parked for the eleventh lunar night just north of the crater Leonid. The rover did not respond to commands to begin operations when the Sun rose on 1 October, and the mission was declared over on 4 October 1971 after several communication attempts. Suggestions that the internal pressure had suddenly dropped would imply that heat from the radioactive heat source could no longer be distributed through the pressurized compartment. The rover had been driven 9.93 km (Karachevtseva *et al.*, 2013), according to LRO image track measurements. The original maps suggested it had driven about 10.5 km based on engineering data, which were affected by slipping wheels and other problems.

After Lunokhod 1 was found in LRO images (Figure 183) the APOLLO (Apache Point Observatory Lunar Laser-ranging Operation) laser in New Mexico obtained reflections from its LRR for the first time since 1970 (Murphy *et al.*, 2011). There was some concern that the LRR was not correctly oriented, and APOLLO had been targeting the location proposed by Stooke (2007) without success, but as soon as the new location was tested a strong reflection was obtained. The first reflections were seen on 22 April 2010. Lunokhod 1 is further from the sub-Earth point on the Moon than other reflectors of the time, making it particularly useful for measuring lunar librations.

Table 57 shows the distance travelled per lunar day, with locations of each night stop measured from the lander. These distances are from Karachevtseva *et al.* (2013) and locations are from Figures 185 to 191.

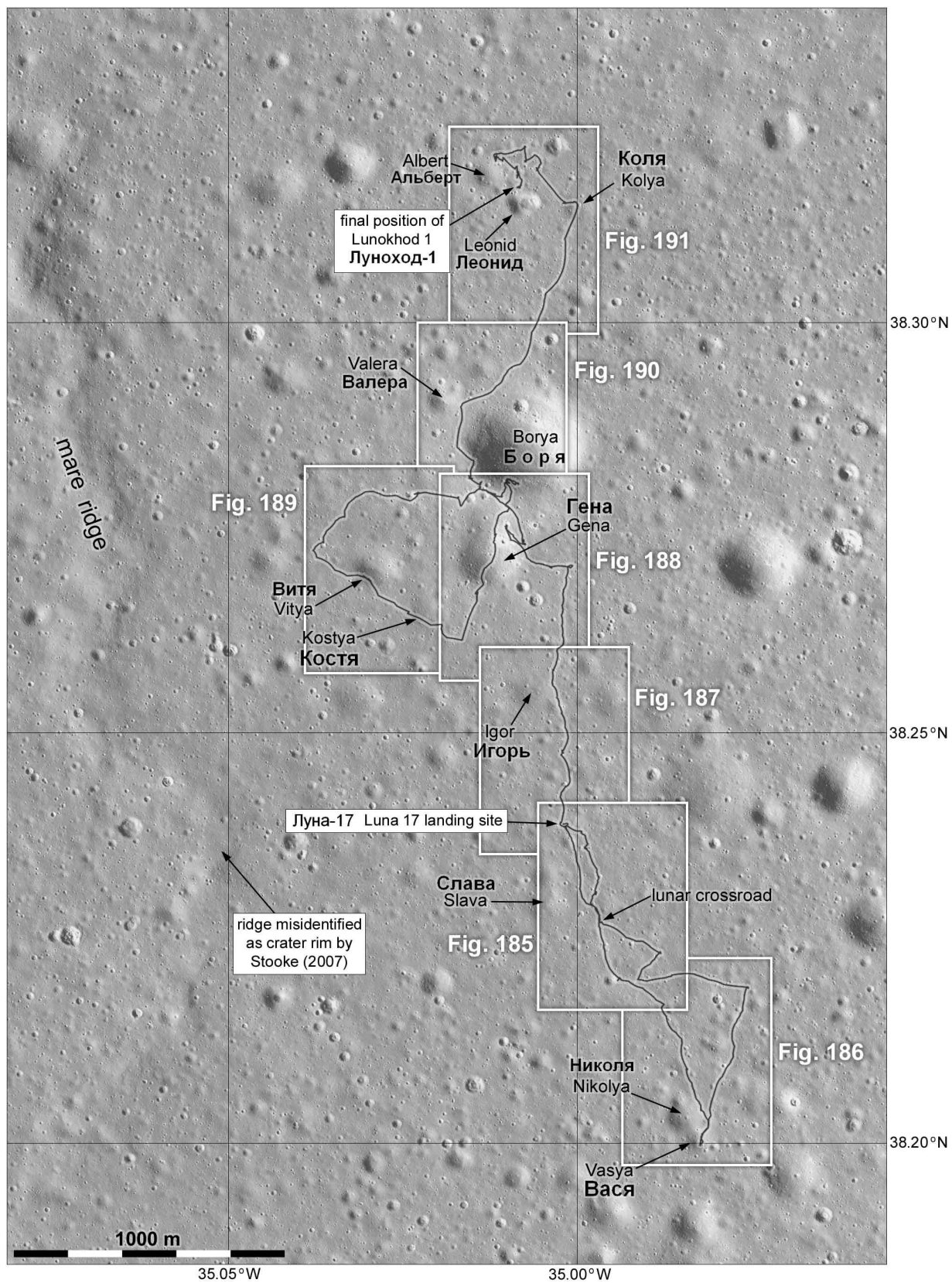


Figure 184. Luna 17 landing site. This serves as an index to the next seven maps.

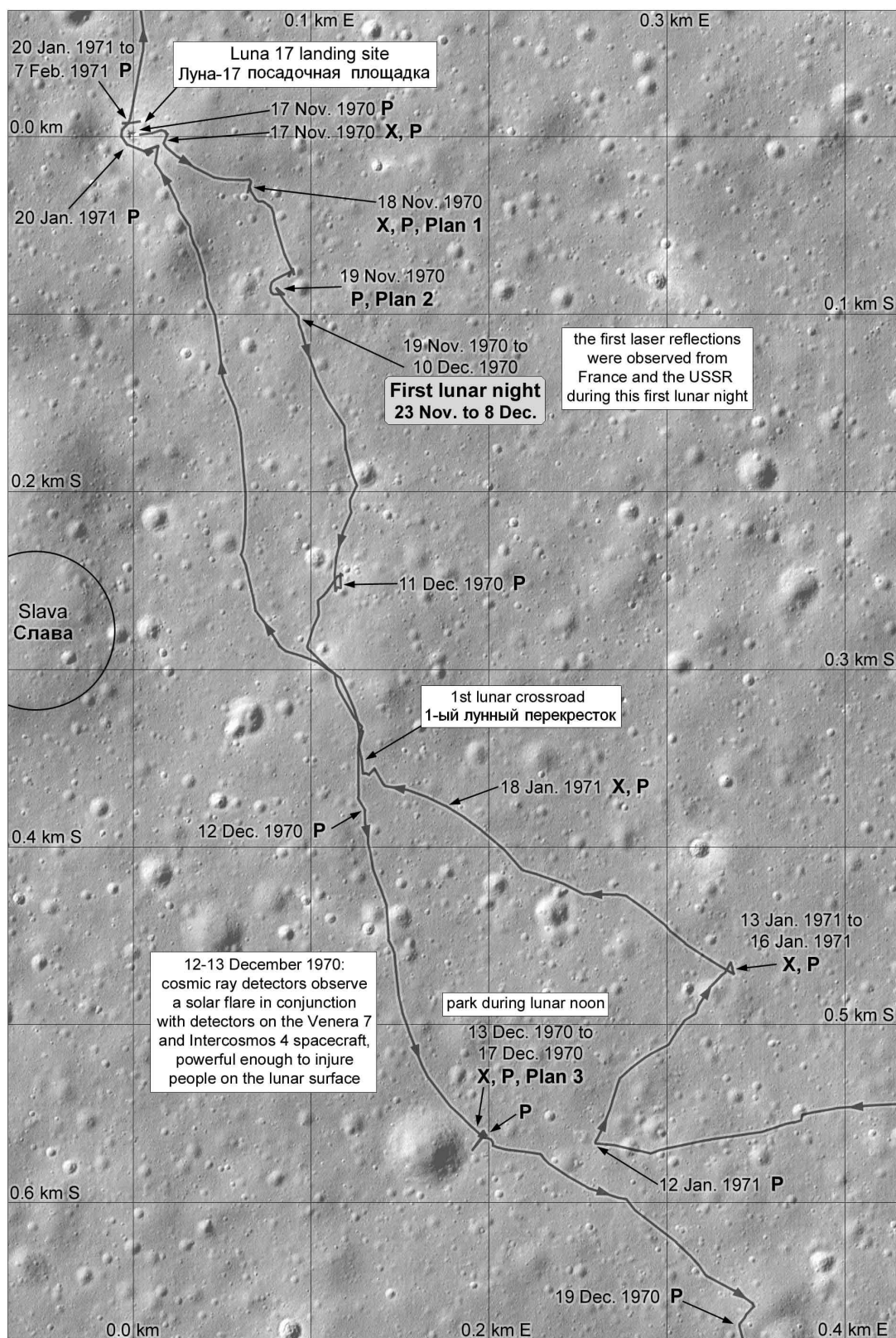


Figure 185. Lunokhod 1 traverse map, section 1. **X**: location of X-ray measurements of soil composition. **P**: locations where panoramic images were obtained. **Plan**: areas mapped at larger scales in Figures 192-193.

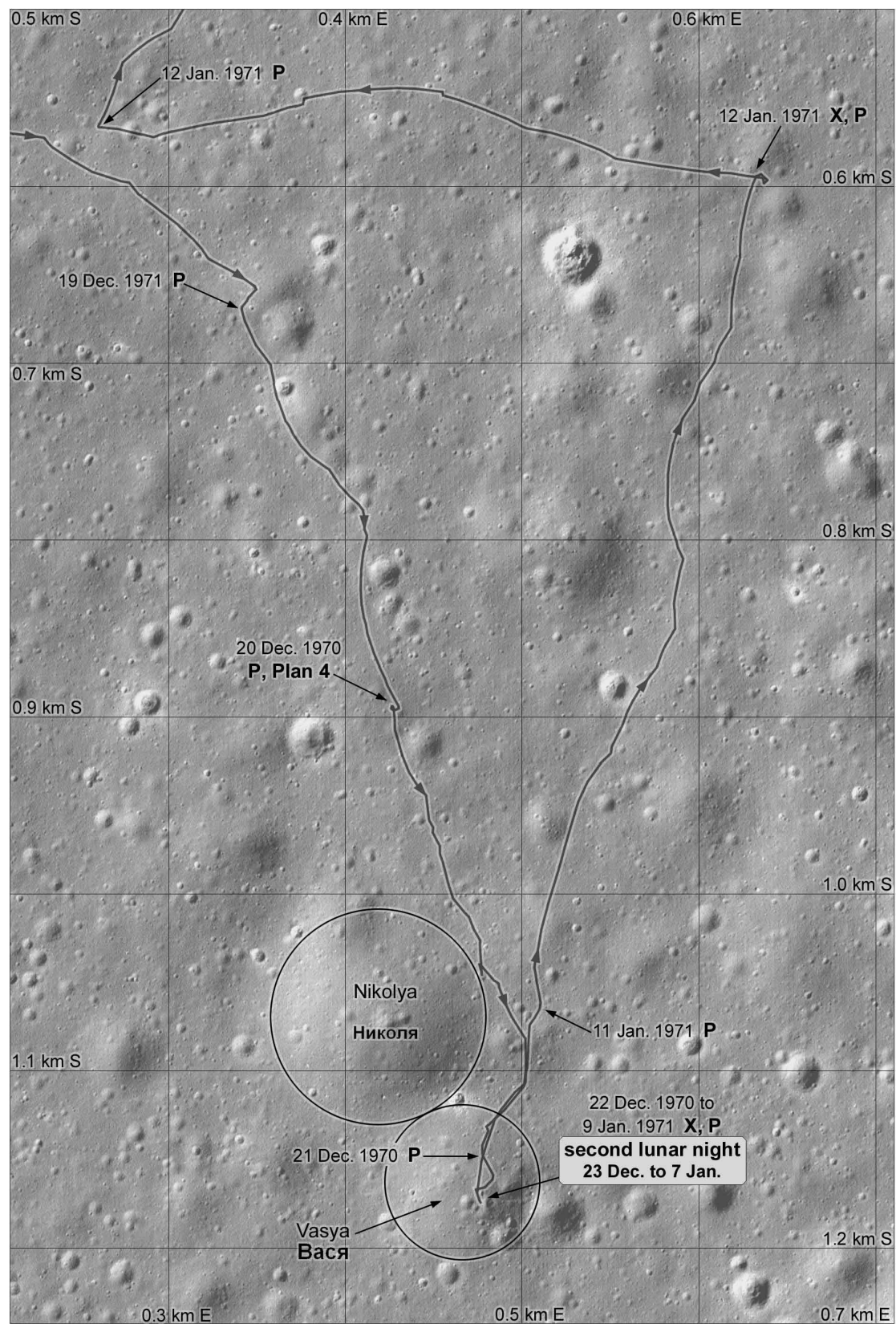


Figure 186. Lunokhod 1 traverse map, section 2.

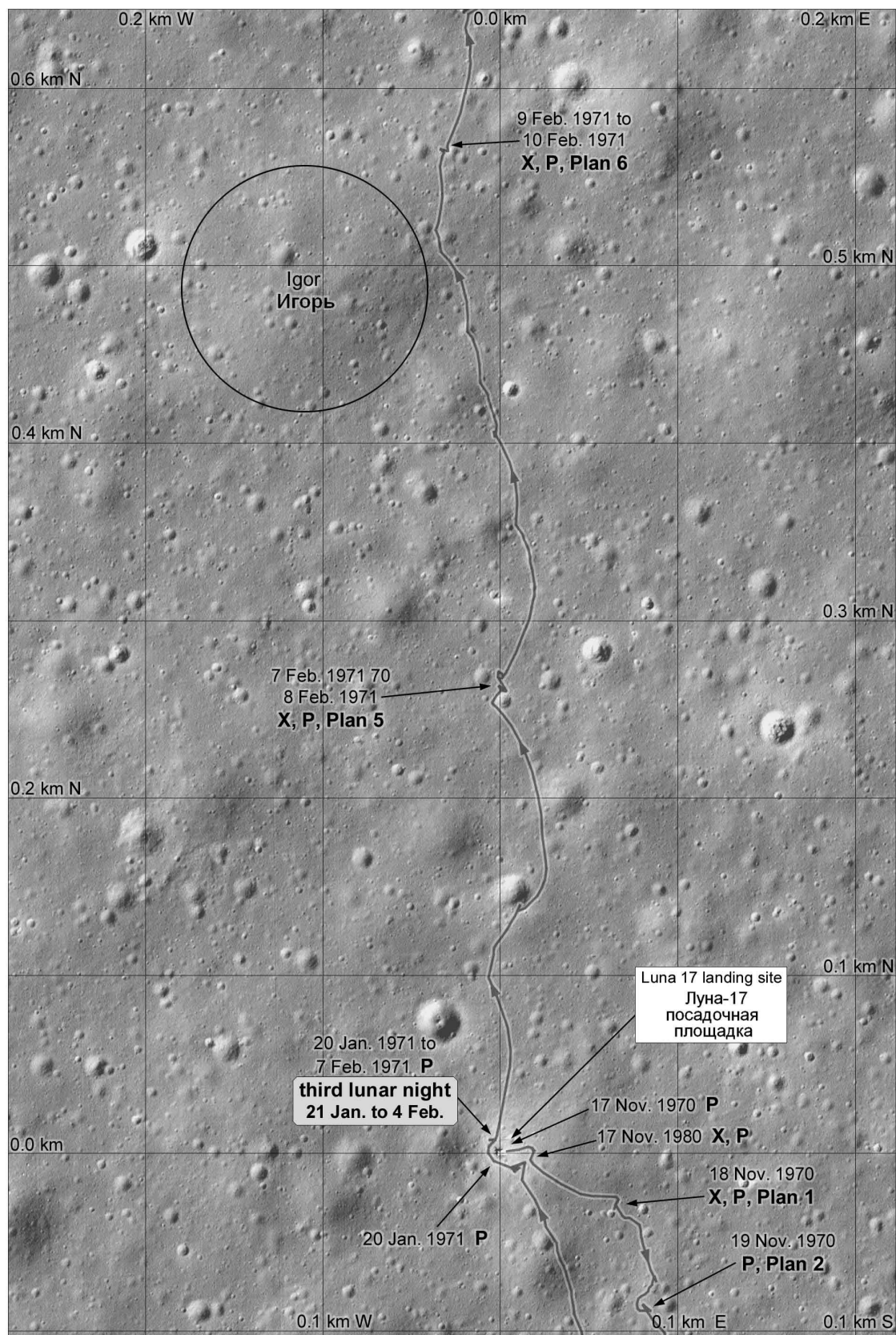


Figure 187. Lunokhod 1 traverse map, section 3.

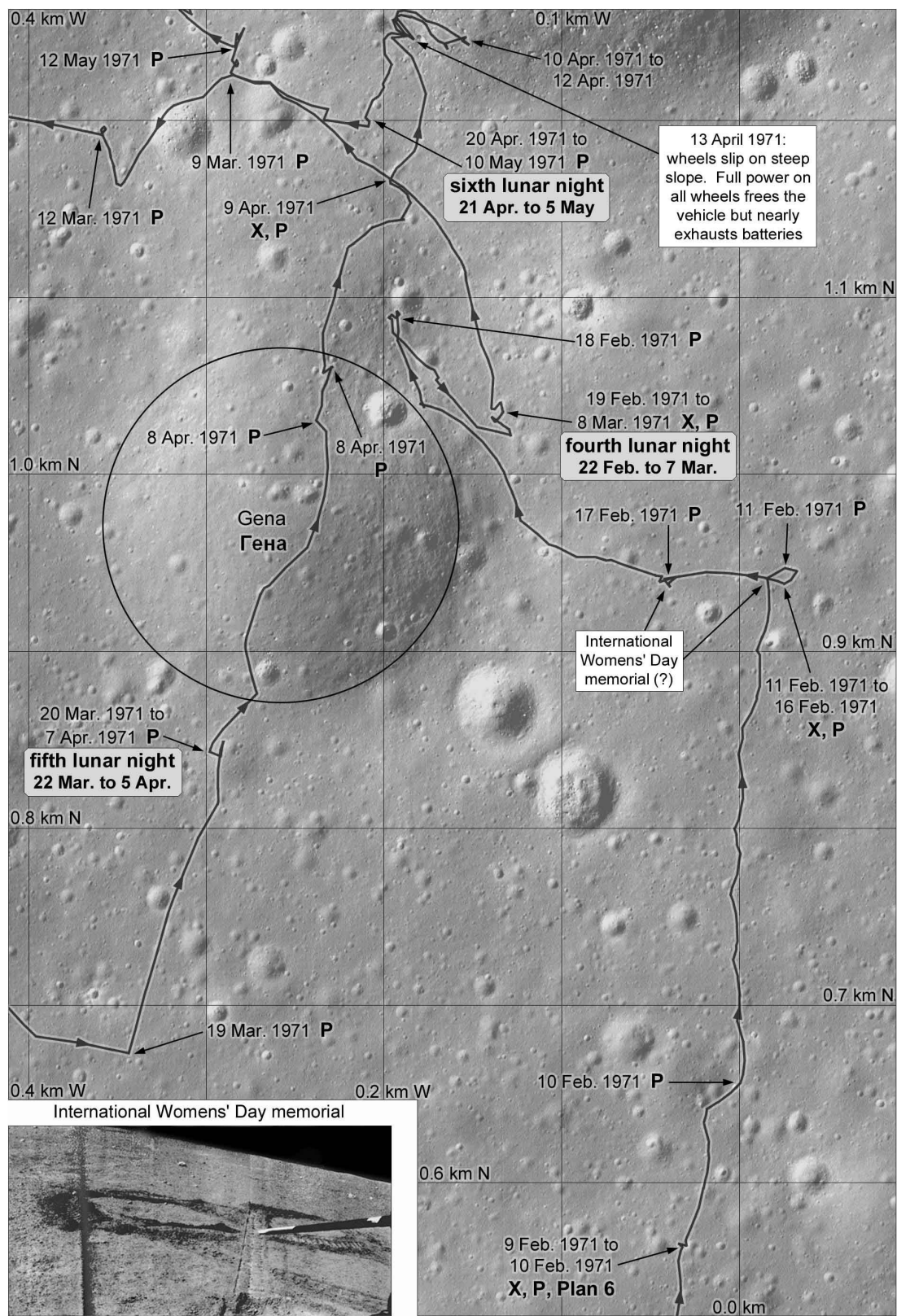


Figure 188. Lunokhod 1 traverse map, section 4. Inset: tracks suggesting a figure 8, represented as a memorial to International Women's Day on 8 March.

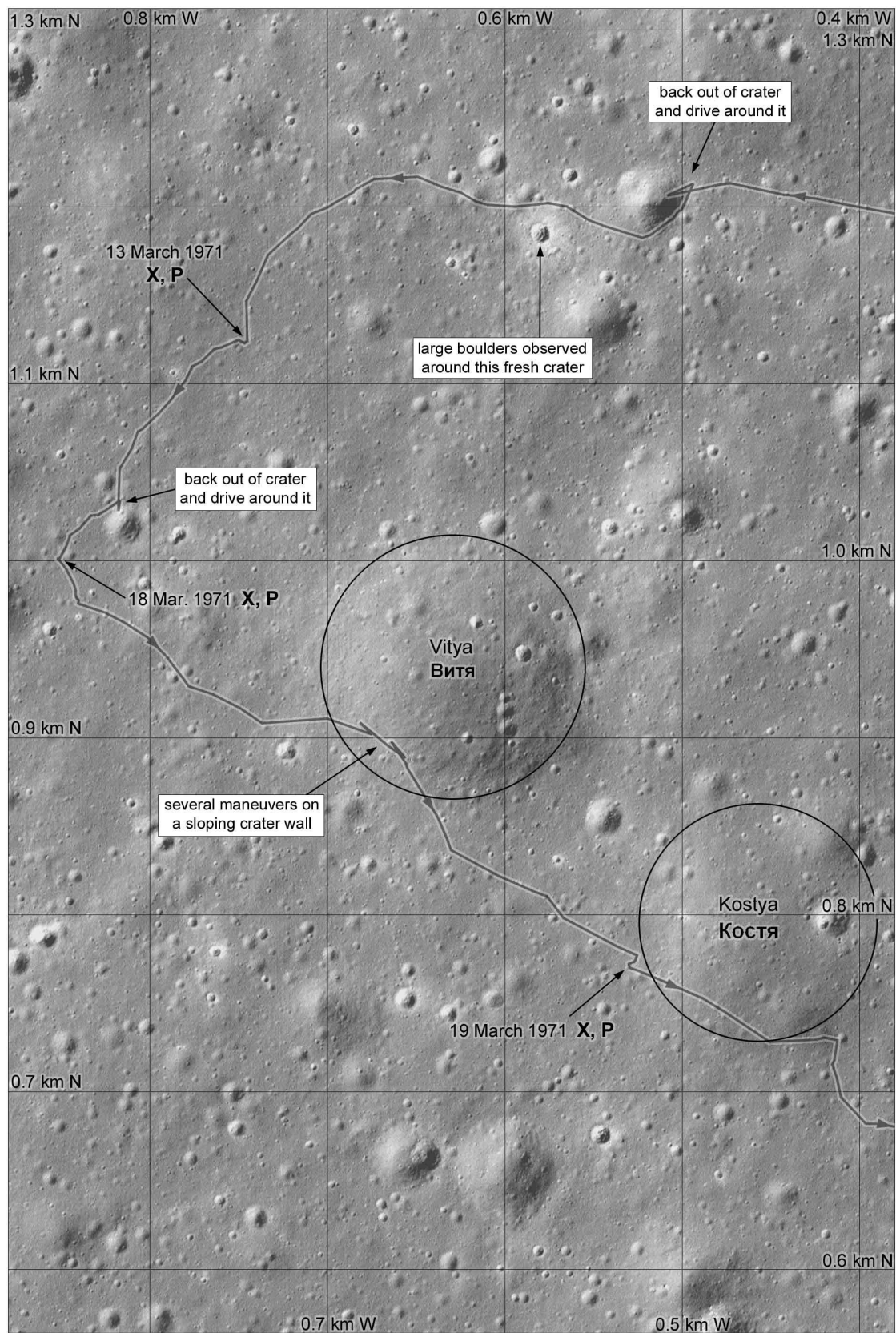


Figure 189. Lunokhod 1 traverse map, section 5.

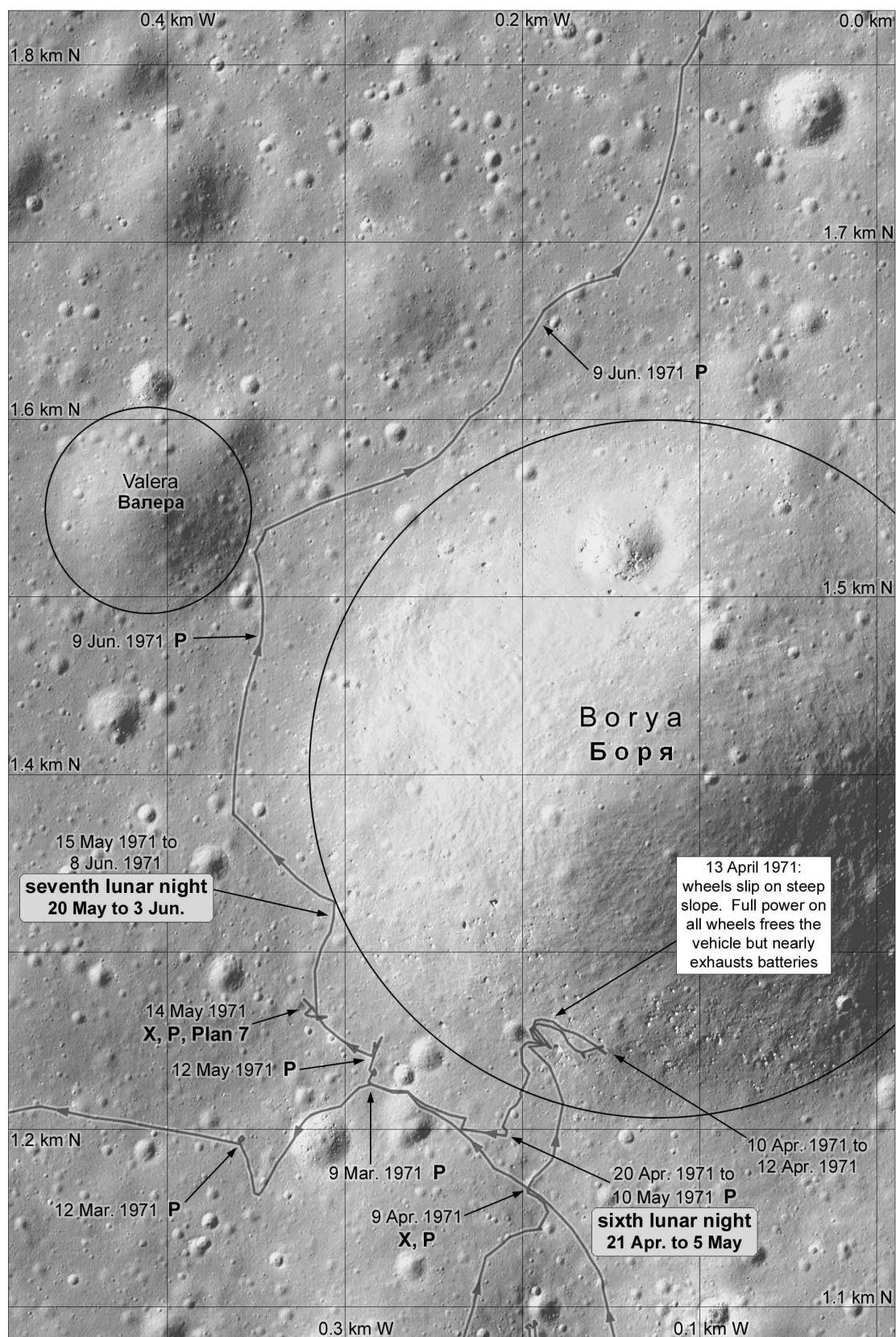


Figure 190. Lunokhod 1 traverse map, section 6.

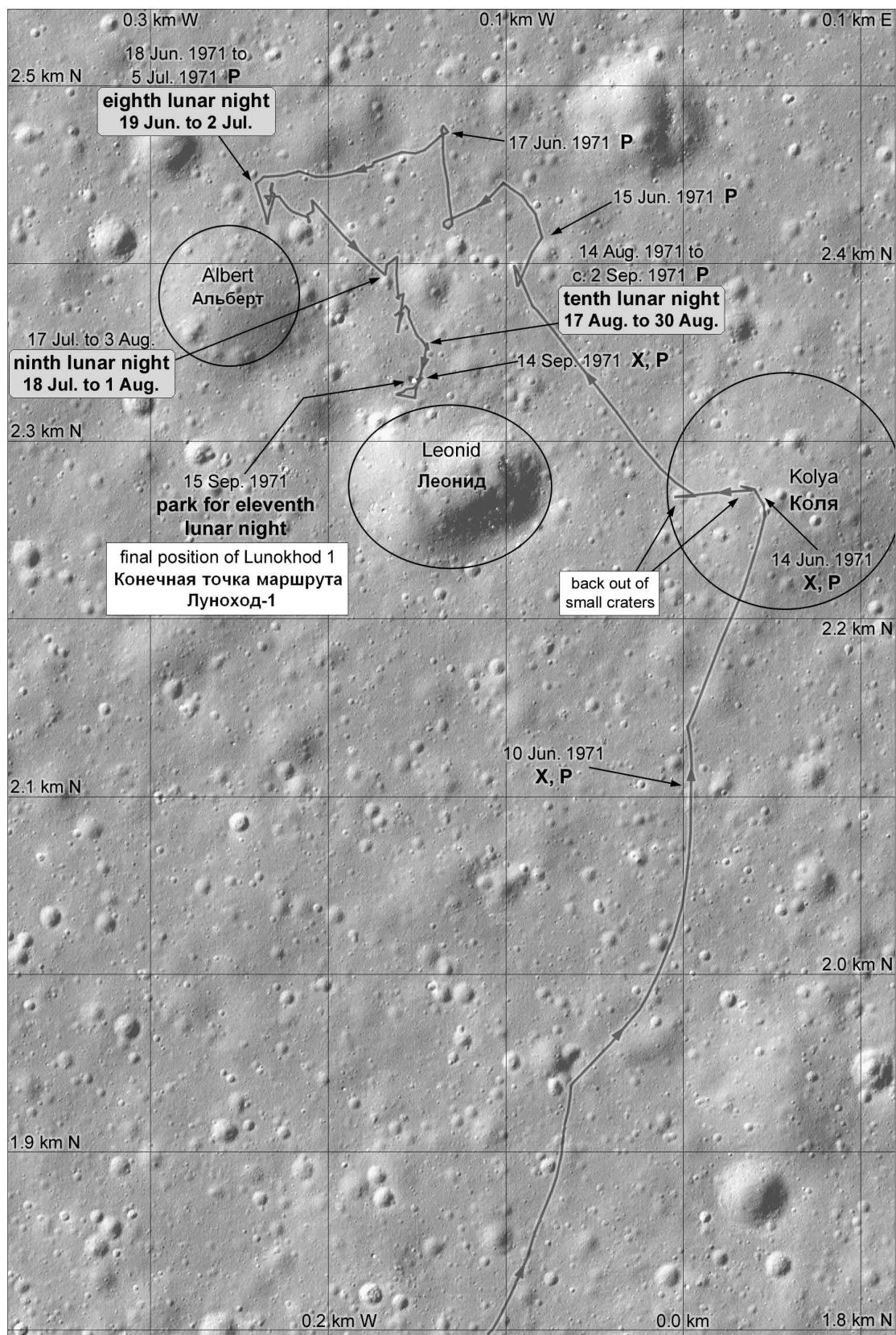


Figure 191. Lunokhod 1 traverse map, section 7.

Table 57. Lunokhod 1 traverse distances per lunar day

Lunar day	dates	Distance Travelled*	end of day location (from lander, measured from Figures 185-191)	
			north or south	east or west
1	17-24 November 1970	232 m (195)	100 m S	90 m E
2	8-23 December 1970	1392 m (1524)	1175 m S	475 m E
3	7-21 January 1971	1897 m (1936.5)	10 m N	5 m E
4	7-20 February 1971	1531 m (1572.5)	1030 m N	130 m W
5	7-20 March 1971	1936 m (2015)	845 m N	295 m W
6	6-20 April 1971	715 m (1022)	1200 m N	210 m W
7	6-20 May 1971	269 m (192)	1320 m N	310 m W
8	4-11 June 1971	1508 m (1560)	2450 m N	240 m W
9	3-17 July 1971	197 m (220)	2390 m N	170 m W
10	2-16 August 1971	154 m (215)	2350 m N	150 m W
11	8-15 September 1971	100 m (88)	2330 m N	160 W

* distances travelled are from Table 4 in Karachevtseva *et al.* (2013). measured from LRO images and GIS maps. Values in parentheses are contemporary estimates from the same source.

LRO images revealed that the published map should be considered somewhat schematic, and some features were difficult to reconcile with the new images. This is not surprising considering the difficulty of mapping from surface images with very limited coverage. In particular the largest crater on the map, a subdued 500 m diameter crater southwest of Borya which was used by Stooke (2007) to try to locate the landing site, does not exist as anything more than a few shallow depressions. New maps were constructed using LRO images and GIS software (Karachevtseva *et al.*, 2013), and names for craters along the traverse were approved in 2012. No craters were named at the time of the mission. The craters were given the Russian diminutive forms of the first names of people associated with the mission (Table 58).

Table 58. Crater names at the Lunokhod 1 landing site

Russian name	English form	Full name	notes
Альберт	Albert	Albert E. Kozhevnikov	Flight engineer
Боря	Borya	Boris B. Nepoklonov	Science team leader
Валера	Valera	Valeri M. Saplanov	Antenna operator
Вася	Vasya	Vasili I. Chubukin	Reserve driver
Витя	Vitya	Vikenty G. Samal	Navigator
Гена	Gena	Gabdulkhay G. Latypov	Driver
Игорь	Igor	Igor L. Fyodorov	Commander
Коля	Kolya	Nikolai Ya. Kozlitin	Antenna operator
Костя	Kostya	Konstantin K. Davidovsky	Navigator
Леонид	Leonid	Leonid Ya. Mosenzov	Flight engineer
Николя	Nikolya	Nikolai M. Yermenko	Commander
Слава	Slava	Vyacheslav G. Dovgan	Driver

The detailed plans in Figures 192 and 193 are adapted from figures in Vinogradov (1971b). They show the locations of craters and rocks in areas which were selected for detailed mapping, as well as the pattern of rover operations in each location. They also indicate locations at which one or more panoramic images were made. The area immediately surrounding the Luna 17 landing site (Figure 192A) was mapped using a composite of the eight best LROC images augmented by details from Lunokhod 1 images. The lander made two visible footpad impressions during the touchdown, and its rocket exhaust disturbed soil on its southwest side. The ramps were lowered and the controllers drove Lunokhod 1 off the eastern ramp on 17 November.

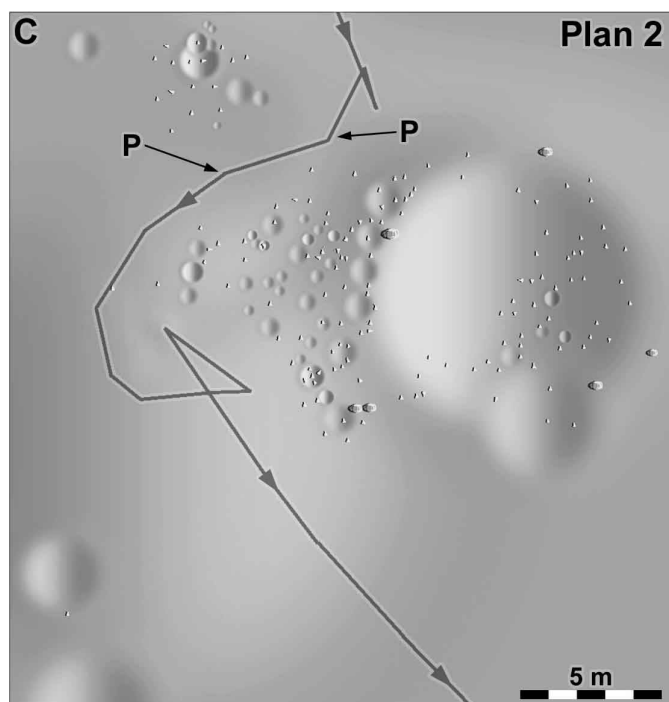
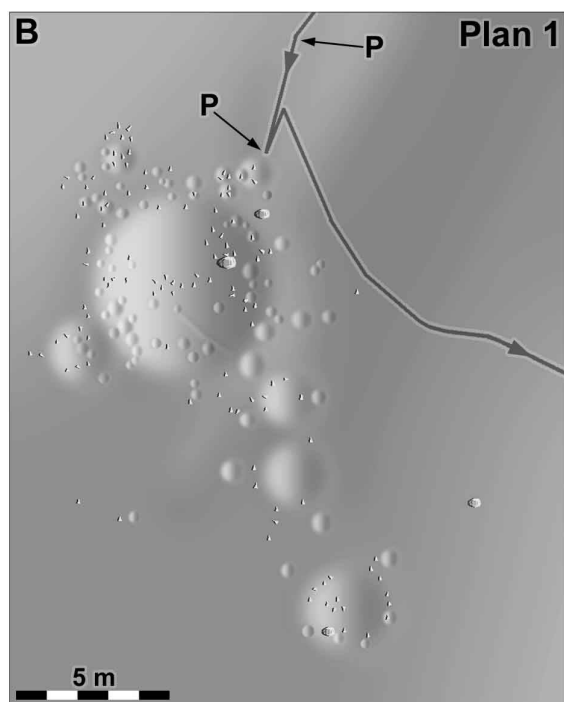
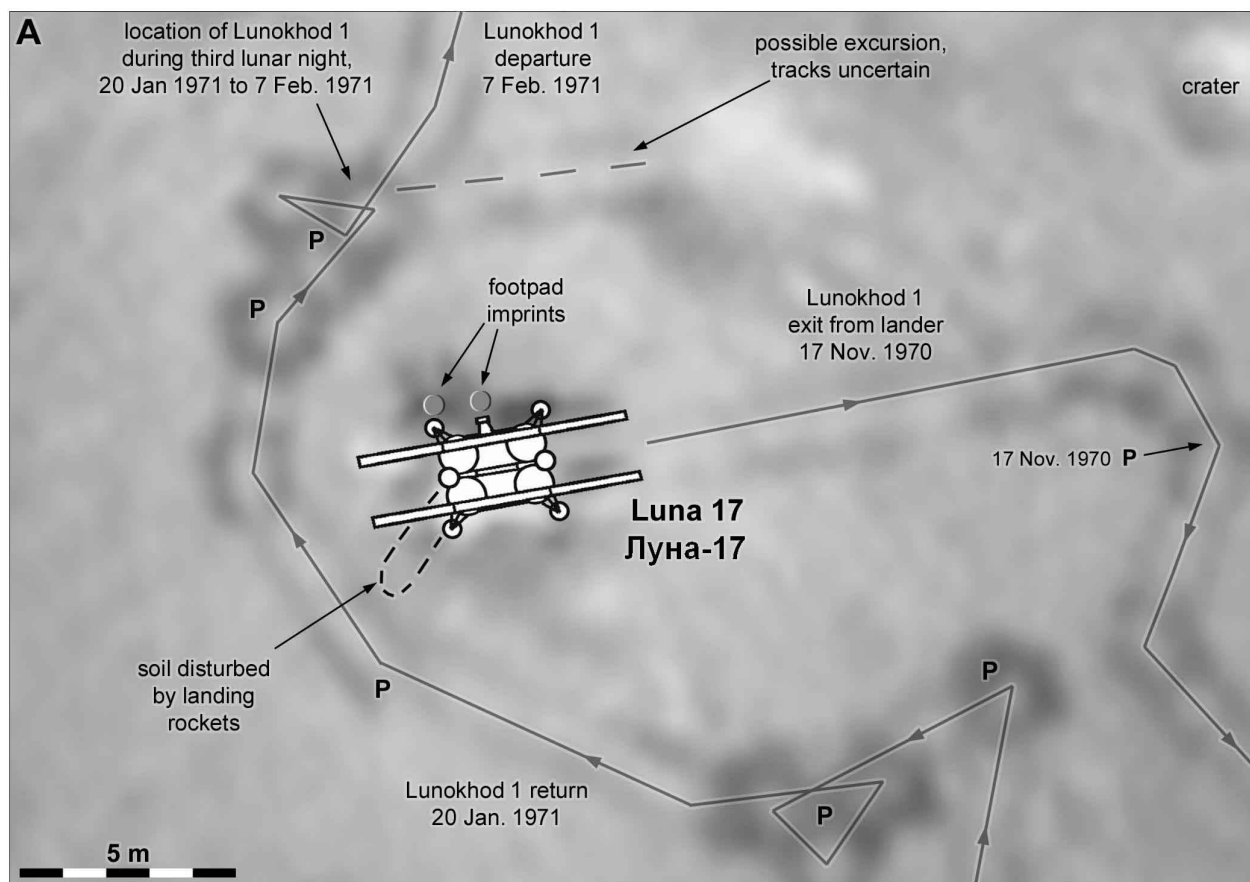


Figure 192. Lunokhod 1 large scale plans. A: Luna 17 landing area. The image is a composite of eight LROC images. B: Plan 1 area. C: Plan 2 area. P: panorama locations.

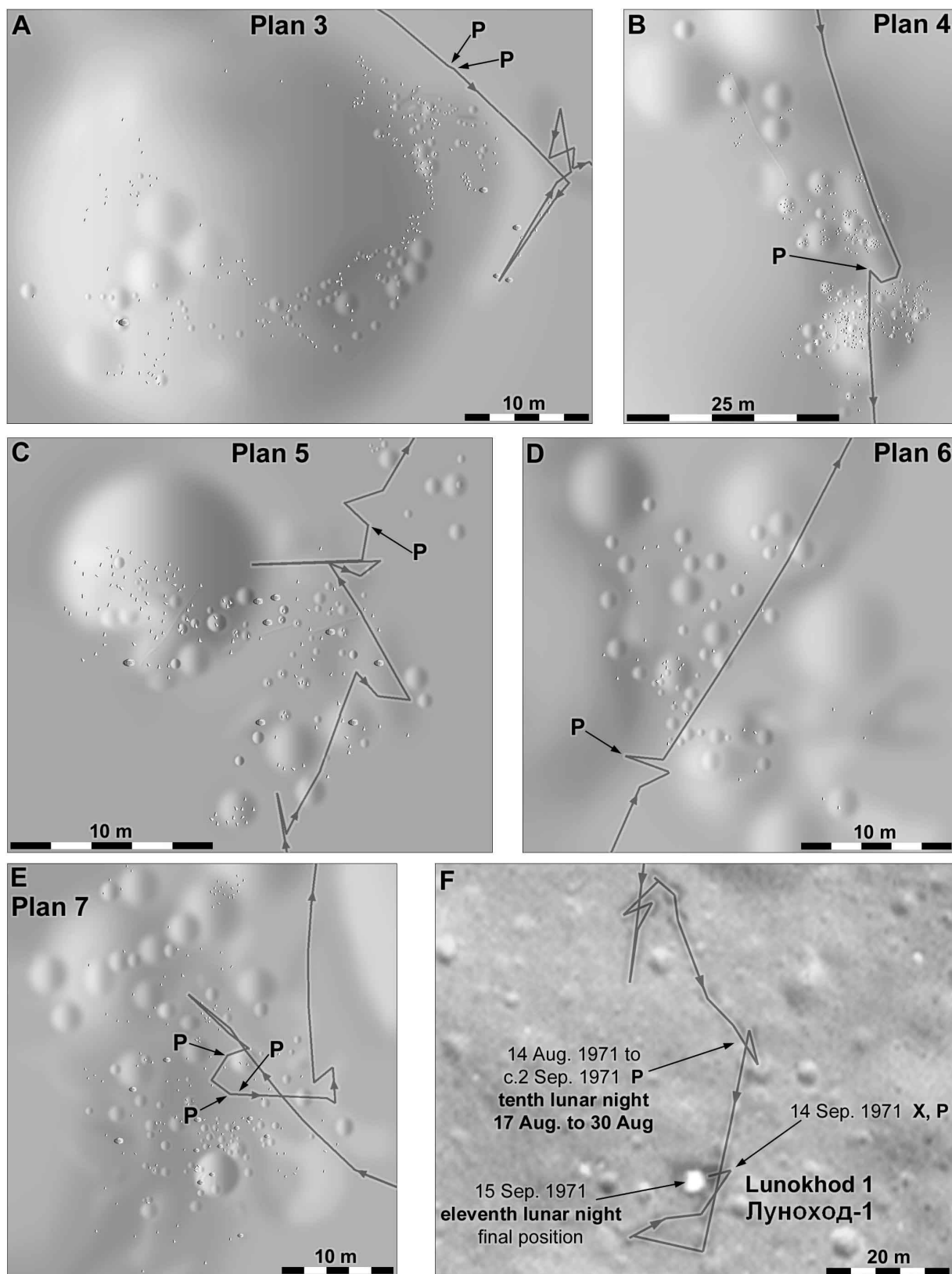


Figure 193. Lunokhod 1 large scale plans. A-E: Plans 3 to 7 modified by P. Stooke from Vinogradov (1971b). F: Lunokhod 1 final position. The image is a composite of eight LROC images. P: panorama locations.

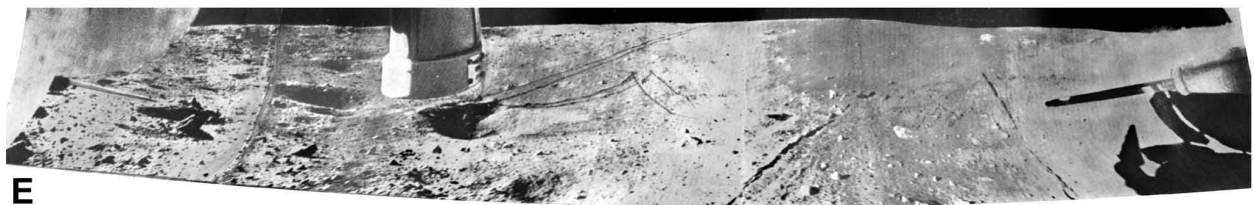
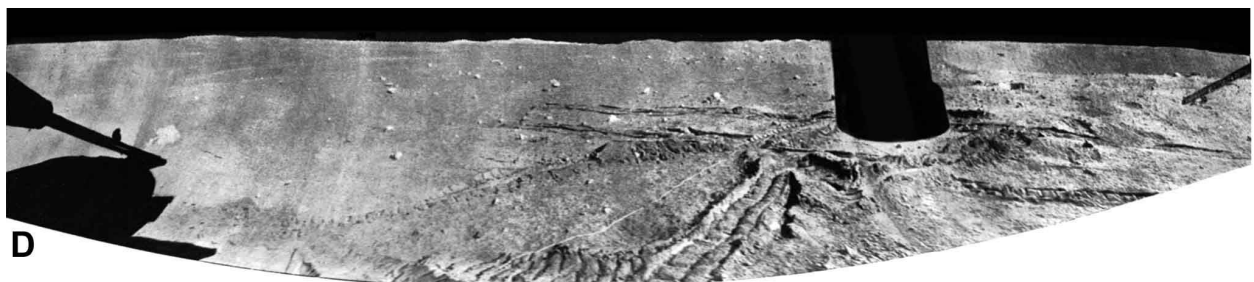
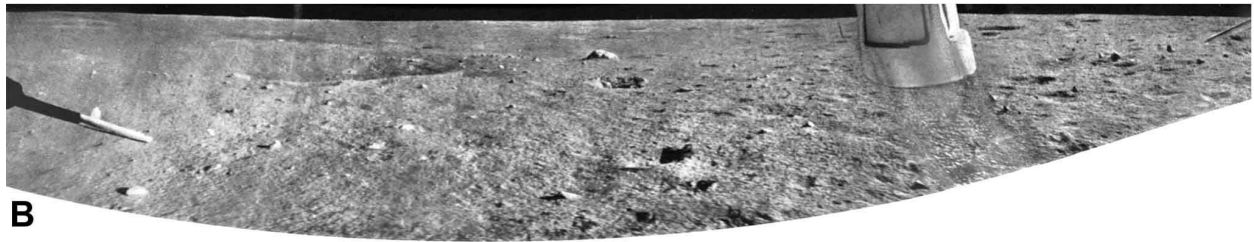
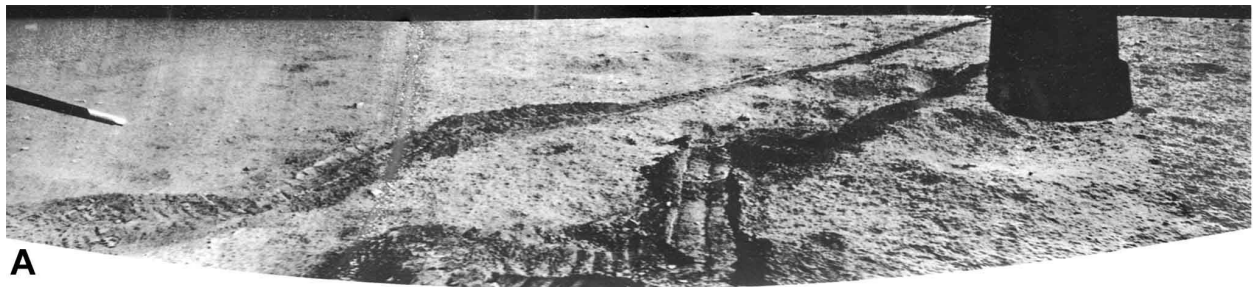


Figure 194: Lunokhod 1 panoramas. A: Panorama made just after Lunokhod left the landing stage on 17 November 1970. B: Plan 2 area looking south. C: Luna 17 landing stage observed when Lunokhod 1 returned to it on 20 January 1971. D: Tracks and distant hills from the Plan 7 area, looking north. E: Panorama made on 21 December 1970 near Lunokhod's southernmost point.

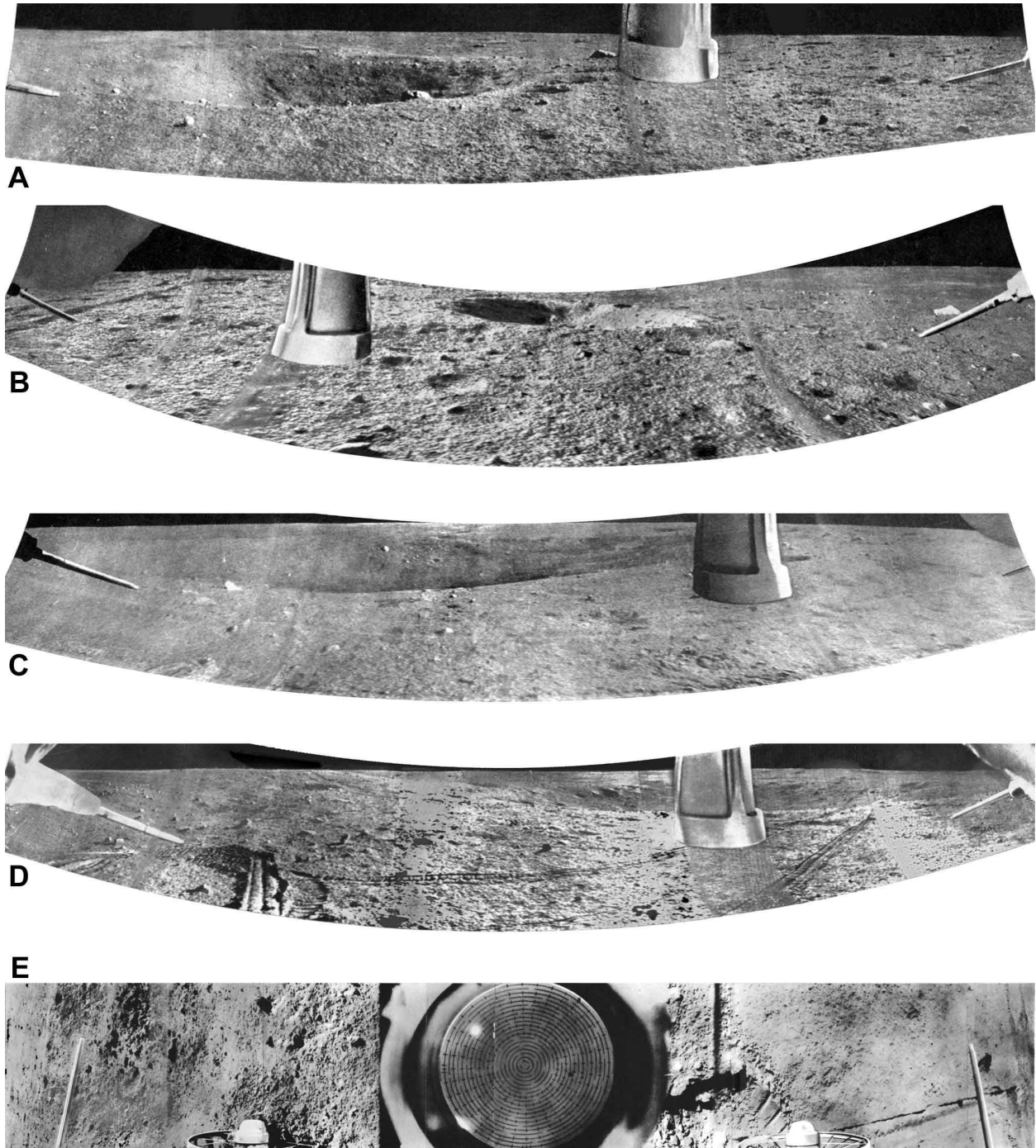


Figure 195. Lunokhod 1 panoramas. A: The plan 2 area, looking southeast. The crater is 8 m in diameter. B: The plan 7 area looking south, showing a fresh 4 m diameter crater. C: The plan 3 area looking southwest. The crater is 30 m across. D: Panorama made on 18 February 1971, looking south. Lunokhod 1 has just emerged from the crater in the background. E: Panorama from one of the downward-facing panoramic cameras, giving a view from the front (left) to the rear (right) with the wheels at the bottom edge. The round object at center is the top view of the bell-shaped orientation indicating device shown in other panoramas. This image was taken in the Plan 1 area.

Several Lunokhod 1 panoramas shown in Figures 194 and 195 have been reprojected to make the horizon level. The region is generally flat, presenting no difficulty to mobility except near larger craters. The bell-shaped object at the top of each panorama is an orientation indicator. Lunokhod 1 images were provided courtesy of V. V. Shevchenko (Sternberg State Astronomical Institute) and A. Wasserman (USGS Flagstaff), and are also available online at the time of writing (2025) at <https://www.planetology.ru/panoramas/lunokhod1.php>

Figures 196A and 196B show hills north of the rover. Figure 196B is a composite of all useful views from Lunokhod 1 of a group of hills seen on the northern horizon. The curved horizon has been rectified and images taken from different positions have been combined to improve quality, though this blurs details in the foreground. The hills were partly visible from the landing site and further south, but were best seen near the northern end of the traverse. The long term plan if the rover continued to operate was probably to continue driving north to improve the view of the hills, which were about 60 km away. They form part of the ridge to the west of Promontorium Heraclides as indicated in Figure 196A.

Figure 196C shows the landing region with dots marking the targets of laser reflection attempts on 5 and 6 December 1970 (Vinogradov 1971b). The white ellipse shows the approximate size of the instantaneous laser-illuminated area at that time, much larger than a comparable illuminated spot in the 21st Century. Reflections were obtained from points 1 and 2, but only very weakly from 3 and hardly at all from 4. The map also shows the contemporary tracking estimate of the site and the actual landing site. This attempt to merge the laser targets with a contemporary map should be considered only approximate.

After Lunokhod 1 was found in LRO images (Figure 183) the APOLLO (Apache Point Observatory Lunar Laser-ranging Operation) laser obtained reflections from its LRR for the first time since 1970. It had not been clear whether the LRR was correctly oriented, and APOLLO had been targeting the location proposed by Stooke (2007), but as soon as the new location was tested a strong reflection was obtained. The first reflections were seen on 22 April 2010.

Murphy *et al.* (2011) summarized early laser detections of Lunokhod 1. Both French and Russian systems detected the reflector during its first lunar night and reportedly again in February 1971 (third or fourth night). A Russian detection was also reported in 1974 (Yagudina *et al.*, 2018), but most attention was directed at the stronger returns from other reflectors in later years and Lunokhod 1 was considered lost. Odile Calame (1975) estimated the location of Lunokhod 1 as 38.3689° N, 35.1537° W, only 3.7 km from the true position, but that position did not produce radar returns (Tryapitsyn *et al.*, 2021). Stooke's location 6 km west of the true landing site was also used to direct lasers without success. Only when LRO found the rover was the Lunokhod 1 reflector detected again.

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<https://doi.org/10.1134/S0038094621040018>
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Wagner, R.V., Nelson, D.M., Plescia, J.B. *et al.*, 2017. Coordinates of anthropogenic features on the Moon. *Icarus*, v. 283, pp. 92-103. <https://doi.org/10.1016/j.icarus.2016.05.011>

Yagudina, E. I., Pavlov, D. A., Tryapitsyn, V. N. and Rumyantsev, V. V., 2018. Processing and analysis of lunar laser ranging observations in Crimea in 1974–1984. *Proceedings of the 21st International Workshop on Laser Ranging*, Canberra, Australia, 5-8 November 2018.



24 November 1970: Cosmos 379

Cosmos 379 was a test flight in Earth orbit of the LK (Lunniy koraby) crewed lunar landing spacecraft, flown here without landing legs or a crew to test its systems. It entered the atmosphere on 21 September 1983.



2 December 1970: Cosmos 382

Cosmos 382 was a test of the Zond (Soyuz) spacecraft which was to carry Soviet cosmonauts to the Moon. It was launched at 17:00 UT on 2 December 1970 from Baikonur into a 190 by 300 km orbit inclined 51.6° to the equator. The Block D upper stage with Zond attached was ignited several times over a 5 day mission to test lunar orbit maneuvers and descent initiation. It was moved to a 303 by 5038 km orbit, then to 1616 by 5071 km and finally to 2577 by 5082 km inclined 55.87° to the equator. It remains in a 2461 by 5208 km orbit. Its purpose was to test the stage through these maneuvers, to test an experimental system to produce drinkable water from moisture in the air during a crewed mission (later used on Salyut space stations), and to use cameras in the fuel tanks to observe fluid behaviour during flight and maneuvers.



1970: Lunar Viking

Kostoff *et al.* (1970) presented arguments for a lunar exploration mission or series of missions using Viking hardware, modified as little as possible from its original Mars objectives to orbit and land on the Moon. The intention was to provide a bridge between the end of Apollo and any future human exploration in the 1980s or later. Six possible missions were described, using the orbiter alone to complete global mapping at about 10 m resolution or targeted 2 m resolution imaging for landing site studies, or using landers for missions to the poles, the limb regions or the farside. In these lander missions the orbiter would function primarily as a communication relay. Global mapping from polar orbit would include infrared mapping to detect thermal anomalies, and the infrared spectrometer might help detect gaseous emissions. A farside lander could function as a geophysical observatory, and instruments optimized for compositional analysis might be placed on a mobile lander or separate rover. A polar lander would use data obtained by its orbiter to select a landing site in a shadowed crater floor, where it would search for surface or sub-surface volatiles. Another lander mission would use its orbiter, carrying imaging, infrared and microwave sensors, to search for transient events such as gaseous emissions, and then direct its lander to the site of activity. If no events were observed during the protracted mapping phase, the lander might be sent to the Aristarchus area where past events were suspected.

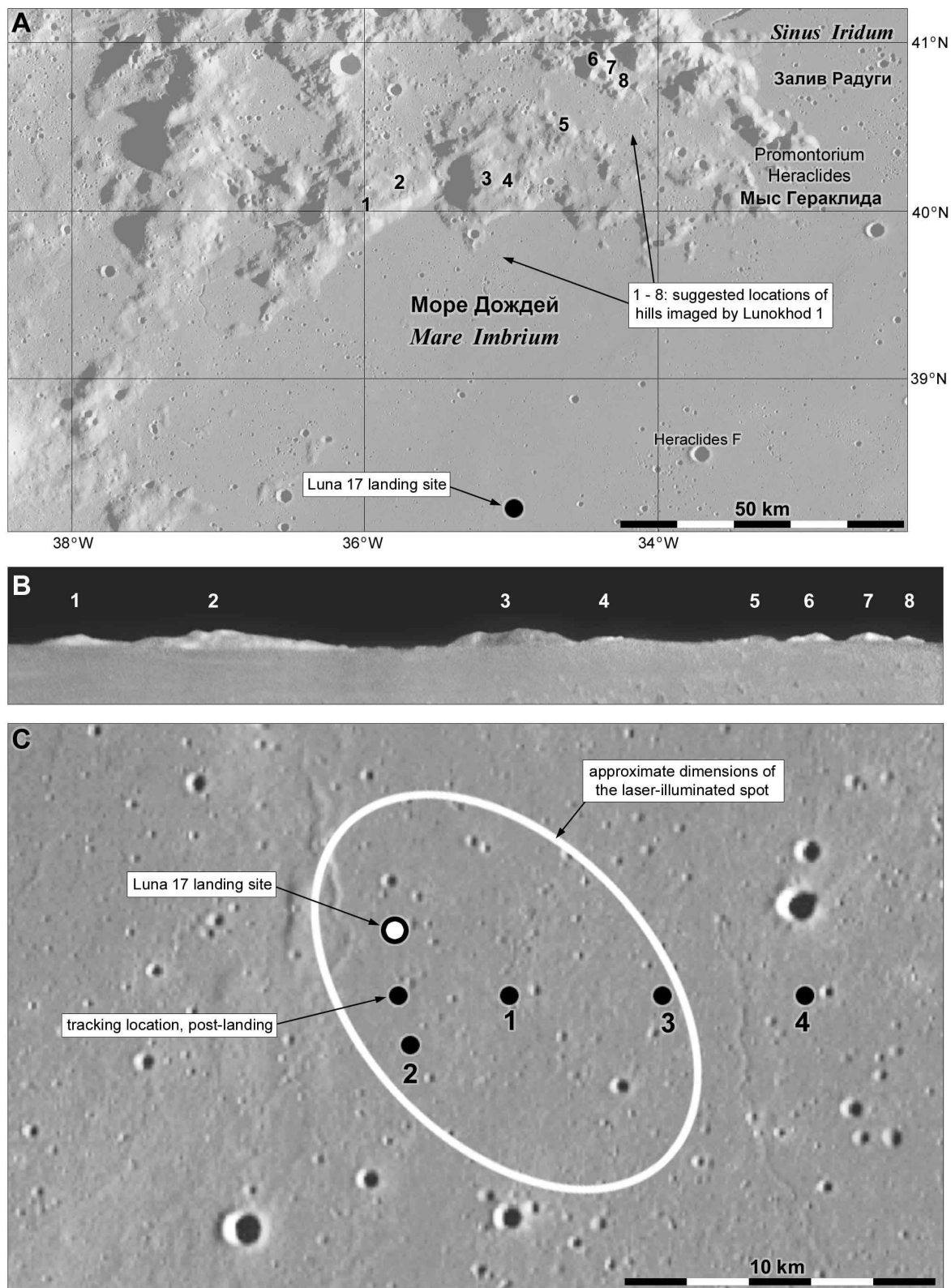


Figure 196: Luna 17 landing area. A: suggested locations of hills seen in Lunokhod 1 panoramas. B: composite of all useful images of the Lunokhod 1 hills. C: laser target locations from Vinogradov (1971b), described in the text.

Kostoff, R. N., Liwshitz, M., Shapiro, S. *et al.*, 1970. *Viking spacecraft for lunar exploration*. Case 340. Bellcomm memorandum B70-06087, 30 June 1970. NASA-CR-113378, N79-72184.



1970: Later Apollo and post-Apollo targets

After the first successful Apollo landings NASA considered numerous options as it contemplated the future of post-Apollo lunar exploration. One report by Hartmann (1970) summarized the role of ALSEP-like emplaced science stations, deployed by astronauts or by automated landers, for lunar science in late Apollo and post-Apollo missions. It recommended that Apollo sites should have relatively simple geology, leaving more complex sites for post-Apollo landings, and that studies of lunar resource extraction should begin as early as 1971. Non-lunar studies including astronomy and biology on the Moon should be delayed until after Apollo, in the mid-1970s, and permanent base site selection should be delayed until the late 1980s to make use of Apollo results. Long range remotely controlled rovers and automated landers like Surveyor were not seen as very useful, but flying units would be desirable, and ALSEP-like stations would be needed at every Apollo site but not at all post-Apollo sites.

Table 59. Suggested Sites for Apollo Lunar Surface Science (Hartmann, 1970)

Site	Type of site	Location	Stay time (days)	Major Objectives
1	Oldest mare	M. Tranquillitatis	1	dating, origin
2	Youngest mare	M. Serenitatis	1	dating, origin
3	Upland plains	Near Maurolycus	1	dating, origin
4	Diatreme (vent)	Alphonsus dark halo crater	3	dating, interior samples
5	Basin ejecta	Oriente ejecta (2nd choice: Fra Mauro)	1	dating, morphology, interior samples
6	Young crater	Censorinus	1	dating, structure, proof of impact origin
7	Upland inter-crater chaos	Near Arzachel	3	dating, lineament origin, nature of ejecta
8	Young crater	Tycho	3	dating, extend Censorinus data to larger crater
9	Volcanics	Marius Hills	3	lunar differentiation, acidic dome lunar volcanic processes
10	central peak	Copernicus	3	origin (post-impact uplift?), dating, composition
11	'ring-dyke'	Flamsteed P	3	origin (extrusion or buried crater?), dating, composition
12	sinuous rille	Rima Prinz	3	Flows (lava or water?), dating
13	highland crater fill	Ptolemaeus	1	nature of crater floor fill in highlands
14	volcanics	basic dome, Marius Hills or Copernicus floor	3	lunar volcanic processes
15	farside highlands	not specified	3	Compare with near side, composition
16	median age mare	M. Orientale	1	rilles and edge effects, dating
17	farside mare	not specified	1	Compare with near side

Table 60. Suggested Post-Apollo Sites from Hartmann (1970)

Composite site - large crater	Person-days	Large sites (mobility over 200 km)	Person-days
large young crater	78	mare-upland contact	30
large crater wall (mass wasting)	4	lineament field	28
scarp or crater wall (sills or dykes)	4	mascon mare	50
central peak	60	linear rille	18
Composite site - dark halo crater	Person-days	medium-old crater floor	24
dark halo crater (vent activity)	10	rift areas	12
diatreme (vent) (deep samples)	4	sinuous rille	18
Composite site - dome		exposed pre-mare ring	24
dome field with varied domes (differentiation)	6	Localized sites (mobility less than 200 km)	Person-days
gentle dome	4	lava flow	16
rough bulbous dome	6	ash flow	8
Composite site - confirmed LTPs	Person-days	cone	4
volcanism	4	rimless crater	12
gas emission analysis	9	patterned ground	4
Composite site - basin ejecta	Person-days	red-blue mare contact	3
emplacement	48	anomalous colour spot	3
sampling deep-seated material	4	wrinkle ridge	18
Composite site - fault scarp	Person-days	mantled ring	30
concentric faults around basin	24	ghost ring	18
mass wasting	4	mid-size young craters	60
sampling deep-seated material	4	small young crater	54
Sites available in any region	Person-days	Sites available in any region	Person-days
gardening	15	any rock outcrop	2
micrometeorite erosion	6	dimple crater	8
solar wind, radiation	2	atmospheric escape	24

Table 61. Apollo sites from Binder and Roberts (1970)

Landing	Site	Notes
1	ALS 2	Apollo 11, representative of old basalts of Mare Tranquillitatis.
2	ALS 7	Apollo 12, another representative old [<i>sic</i>] mare site south of Copernicus.
2b	ALS 5	Apollo 12 backup site, a mix of young mare and Kepler ejecta, lacking the homogeneity of ALS 2 and ALS 7. Should be postponed to a later mission.
3	Fra Mauro	Imbrium basin ejecta blanket, widespread homogeneous deposit.
4	Rima Bode II or Littrow	Rima Bode II: volcanic deposits, possible deep-seated materials, may be too complex for Apollo. Littrow: mare-highland transition, ejecta, too complex for Apollo. Both targets should be postponed.
5	Censorinus NW	Small fresh impact crater, representative of many similar features. May also serve for later studies of impact and ejecta deposition processes.
6	Tycho rim	Large young crater, may also serve for later studies of impact processes.
7	Copernicus central peaks	Large crater, central peaks may provide deep-seated materials. Crater floor deposits may also be suitable for later missions.
8	Descartes	Complex upland, may be volcanic. Better orbital images clarifying geologic units might make it a suitable Apollo site, otherwise it should be postponed.
9	Marius Hills	Cluster of volcanic hills. Many potential sites and scope for later studies.
10	Hadley/Apennine	Rima Hadley, good Apollo site. Proposed long rover traverses may be more suited to a post-Apollo mission.

The report included a list of 17 regions or features of interest (Table 59) and locations within them which would fulfill the goals of Apollo and concluded Apollo was nearly able to fulfill those goals. These sites were independent of the ASSB recommendations and grew out of earlier studies (details....?). At this time Apollo 13 had not been aborted and Apollo 20 had been cancelled, so nine landings were anticipated. Post-Apollo features of interest were also chosen (Table 60) but were not related to specific sites so that Apollo results could be incorporated into the selection process. Some locations might be the same as in Table 59 but would allow more intensive investigation.

The number of person-days at each site was estimated based on the author's field geology experience, and altogether 764 person days would be needed for a minimal but complete program. That might be accomplished with fourteen three person 14-day missions, including some with several visits to one site and others where multiple objectives might be achieved at one site.

For comprehensive regional exploration a permanent base might be needed, and semi-permanent bases at composite sites in the late post-Apollo period might be useful precursors. The Orientale basin was identified as a possible permanent base site rich in scientific targets. Locations on the eastern rim of the basin would be chosen so they would always be in sight of Earth regardless of libration, and deep valleys or locations beyond the limb would provide interference-free sites for radio astronomy.

Another report by Binder and Roberts (1970) outlined a site selection process for post-Apollo missions which would involve the scientific community to a greater degree, rather than being conducted largely within the ASSB. The Board would draw up a long list of interesting sites with science goals and mission requirements for each location, and solicit suggestions for experiments and investigations from the broader scientific community, which would refine the list and shape mission development and site selection. They also looked at sites for the remaining Apollo missions (Table 61), assuming that the main goal for Apollo was to sample sites typical of specific geological units. Sites should be chosen so that the likelihood of sampling the intended unit was high, and complex sites should be postponed to later missions.

The Binder and Roberts study was based on the list drawn up by GLEP on 23 August 1969 (Table 48, 'GLEP modified list' column), updated by substituting the Apollo 12 site (Site 7) for Apollo Site 3 in the GLEP list. The Apollo 12 site is described as old, though it was substantially younger than the Apollo 11 site, but that was not certain at the time this report was compiled. If ALS 5, Rima Bode II or Littrow, and Descartes were dropped from the list of Apollo sites, Binder and Roberts (1970) suggested they be replaced with highland plains near Maurolycus, the Flamsteed Ring (rim of Flamsteed P), young basalts in Mare Serenitatis and dark halo craters in Alphonsus.

Binder, A. B. and Roberts, D. L., 1970. *Criteria for Lunar Site Selection*. Report No. P-30. Astro Sciences Center, I.I.T. Research Institute, Chicago, Illinois, January 1970.

Hartmann, W. K., 1970. *Lunar Surface Scientific Experiments and Emplaced Station Science*. Report no. P-31, Astro Sciences Center, I.I.T. Research Institute, Chicago, Illinois, 9 March 1970.



31 January 1971: Apollo 14

Apollo 14, the third successful astronaut landing on the lunar surface, was launched from pad 39A of the Kennedy Space Center at 21:03 UT on 31 January 1971 after a 40 minute weather-related delay. It entered a parking orbit 12 minutes later, and the translunar injection burn began at 23:38 UT. A trajectory correction was used to counteract the launch delay. The Command-Service Module (CSM), with the call sign 'Kitty Hawk' separated from the S-IVB stage at 00:06 UT on 1 February, and after some initial problems it was able to dock with the LM at 02:00 UT and extract it from its storage space in the S-IVB.

The S-IVB upper stage was placed on a lunar impact trajectory and crashed (Figure 212) at 8.09° S, 26.02° W in contemporary coordinates, updated from LRO as 8.179° S, 26.031° (Wagner et al., 2017). The impact occurred on 4

February at 07:41 UT with a velocity of 2.54 km/s and a path inclined 21° off vertical. A second CSM trajectory correction was made on 2 February and a third on 4 February, with lunar orbit insertion at 07:00 UT on that day.

The Apollo 14 Commander was veteran astronaut Alan B. Shepard, Jr. (1923-1998; also flew on Mercury Redstone 3, the first U. S. suborbital astronaut mission). Stuart A. Roosa (1933-1994) was the Command Module Pilot, and Edgar D. Mitchell (1930-2016) was the Lunar Module Pilot. The backup crew consisted of Eugene Cernan (Gemini 9, Apollo 10, later Apollo 17), Ronald Evans (later flew on Apollo 17) and Joe Engle (STS-2 and STS-51I).

The Lunar Module (LM), call sign 'Antares', flown by Shepard and Mitchell, separated from the CSM at 04:51 UT on 5 February and landed at 09:18 UT at the pre-planned landing site at 3.6° S, 17.5° W in contemporary coordinates (updated from LRO data as 3.646° S, 17.472° W by Wagner *et al.*, 2017), about 25 km north of the rim of Fra Mauro crater (Figures 197, 198). The astronauts made two EVAs on 5 and 6 February for a combined 9 hours, 23 minutes on the lunar surface. They deployed the second ALSEP scientific instrument package (Apollo 12 being the first) and collected 42.9 kg of regolith and rocks. Meanwhile Roosa undertook an extensive series of photographic and visual observations from orbit.

The LM lifted off at 18:49 UT on 6 February after 33.5 hours on the Moon. The LM docked with the CSM at 20:36 UT. 42.3 kg of lunar samples, and film and other materials were transferred into the CSM. Then the LM was separated at 22:48 UT and deorbited, impacting at 3.42° S, 19.67° W on 8 February at 00:45 UT to create a new seismic signal for the Apollo 12 and 14 seismometers (Figure 213). The trans-Earth injection burn began at 01:39 UT on 7 February, and was followed by a small correction on 8 February.

The CM separated from the SM at 20:36 UT on 9 February and splashed down at 27° 1' S, 172° 39' W in the Pacific Ocean, about 1200 km south of Samoa, at 21:05 UT after a total flight time of 216 hours, 2 minutes. The spacecraft and crew were recovered by the USS New Orleans and placed in quarantine, as the previous landed crews had been, but the need for quarantine was so doubtful that it was abandoned after this flight. The Apollo 14 Command Module is on display at the Astronaut Hall of Fame, Titusville, Florida.

Figure 197 shows the landing area. The Fra Mauro Formation is a thick layer of material ejected from the Imbrium basin to the north. The entire area shown here was covered with this deposit, and depressions in the landscape were later filled with lava flows, leaving higher terrain unburied. A broad north-south ridge of this ejecta overlaps the northern rim of Fra Mauro crater and contains the Apollo 14 landing site (Figure 197B). Closer views are given in Figure 198, and an Apollo 13 version of the site is shown in Figure 169D.

The targeted landing point was on the floor of a broad valley west of a low ridge, with a prominent geological target of the mission, Cone crater, on a spur of that ridge. The landing site was on a roughly flat area between two crater groups, Doublet and Triplet (Figures 198C, 199, 200). South crater, part of the Triplet group (Figure 200B), was later renamed South-Apollo to avoid confusion with another South crater on the Moon at 58.0° N, 50.8° W. The site was about 150 m south of the Apollo 13 landing target (Figure 199D).

Apollo 14 carried two 70-mm Hasselblad cameras, two Hasselblad data cameras, three 16-mm Maurer automated data acquisition cameras, a lunar surface stereoscopic camera and a special Hycon topographic mapping camera for use in photographing future landing sites. The Hycon camera suffered a shutter problem that reduced the quality of its images. Despite this, they were used to search for alternatives to the Apollo 16 landing site (Figure 215). Samples collected on the lunar surface included six core-tubes, a sub-surface (uncontaminated) soil sample, and a sample of regolith contaminated by descent engine exhaust from below the LM.

Apollo 14 EVA plans are illustrated in Figure 199 (MSC, 1971a). The three maps in Figures 199A, B and C show plans for the same three landing targets considered for Apollo 13 (Figures 171, 172), but note that sites 1 and 3 have been moved slightly from those intended for Apollo 13. The EVAs also differed in many details from those of Apollo 13. For all three of these landing points the basic plan was as follows. A contingency sample would be collected immediately after the start of the first EVA, as on previous missions, and after ALSEP deployment a comprehensive sample would be collected nearby (corresponding to the Apollo 12 'selected samples' late in EVA 1). On EVA 2 a fully documented set of samples would be collected.

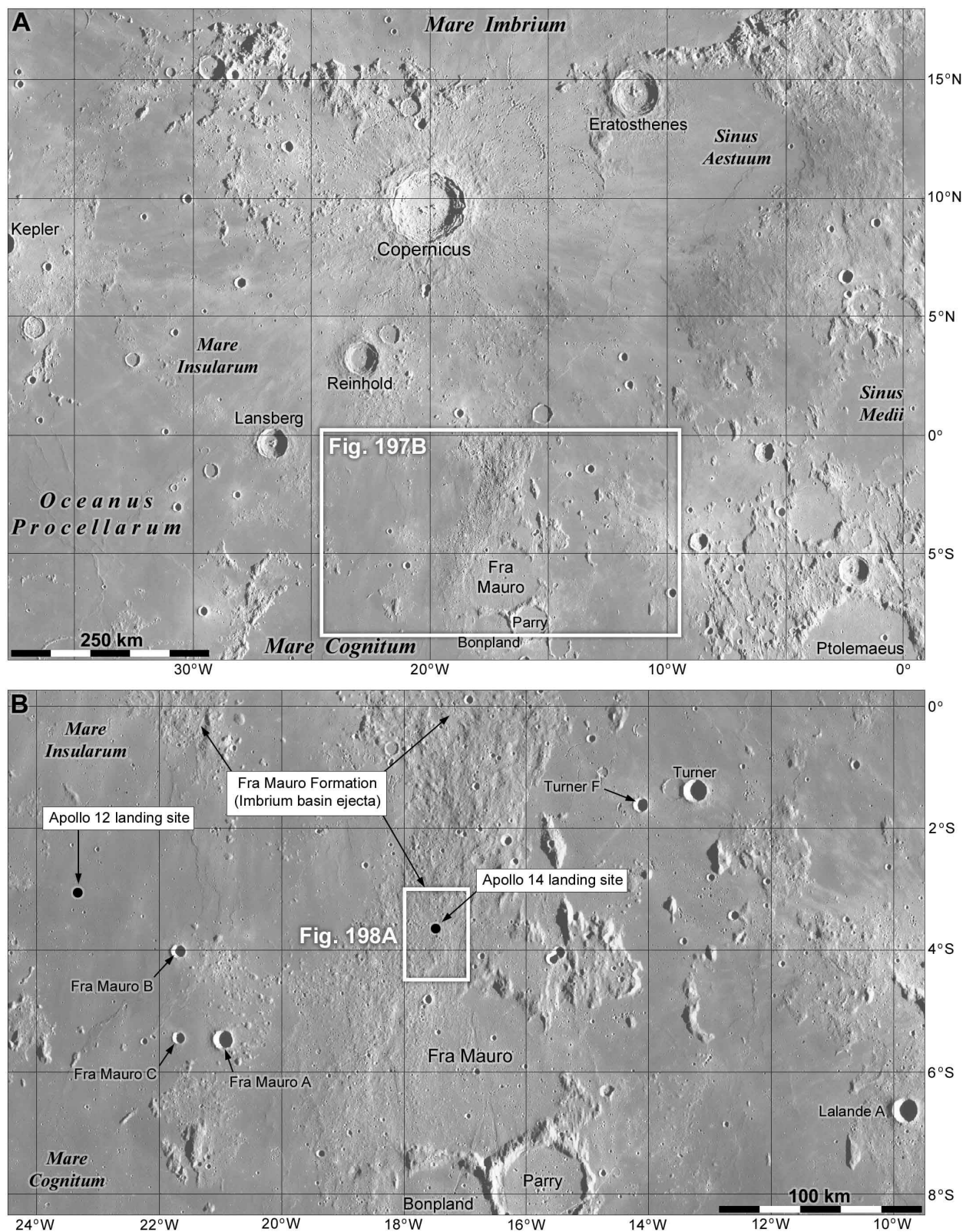


Figure 197. Apollo 14 landing site. A: regional context. B: vicinity of the landing site. The images are LRO wide angle mosaics.

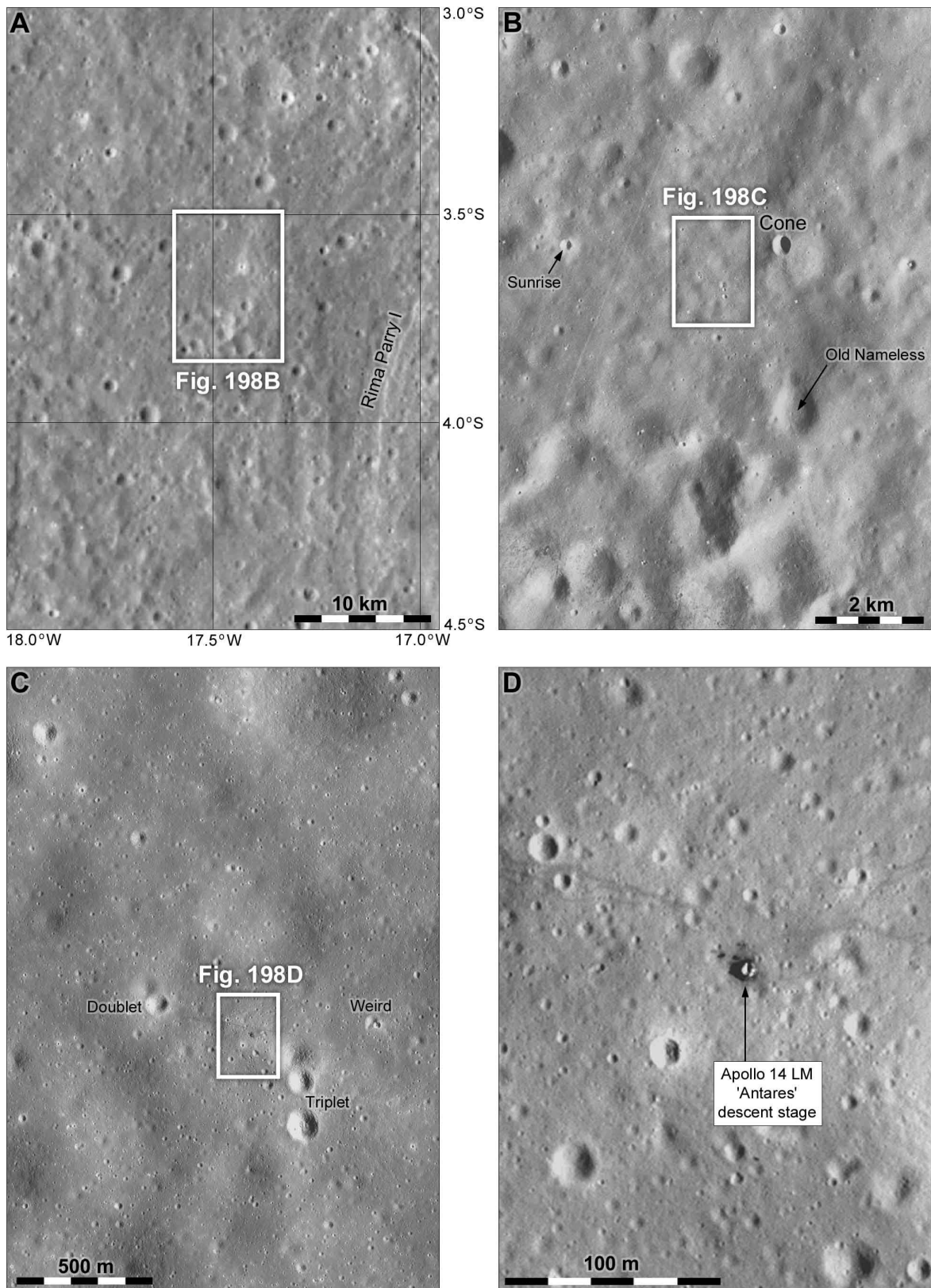


Figure 198. The Apollo 14 landing site. A: LRO wide angle mosaic. B: Lunar Orbiter frame LO3-133-M. C, D: LRO image M114064206.

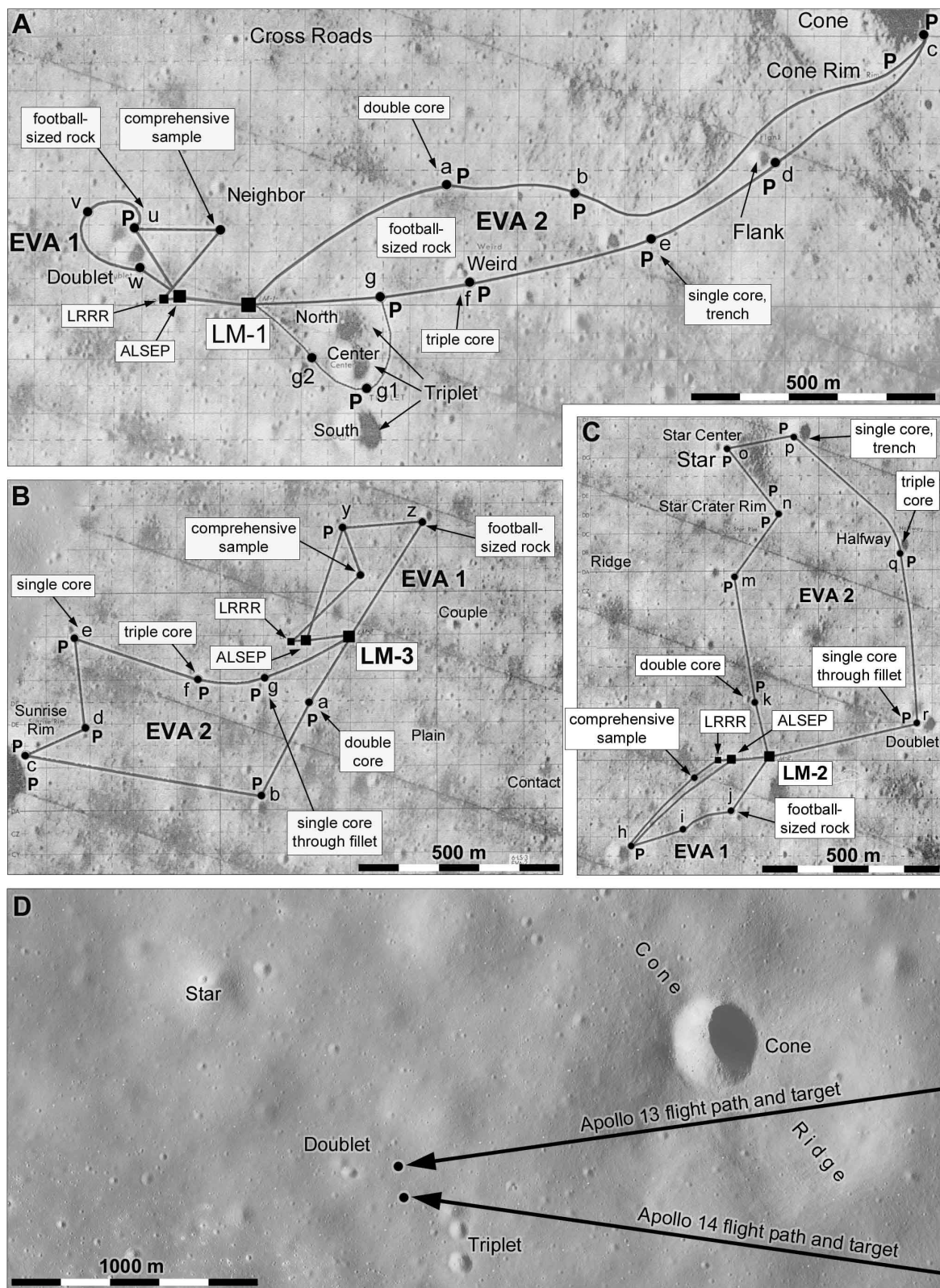


Figure 199. Apollo 14 pre-mission EVA plans and landing trajectory. A, B, C: EVA plans for three possible landing sites (see also Figures 171, 172). **LRRR**: Lunar Ranging Retroreflector. **P**: panorama. D: Apollo 13 and 14 landing trajectories and targets on LRO image M114064206.

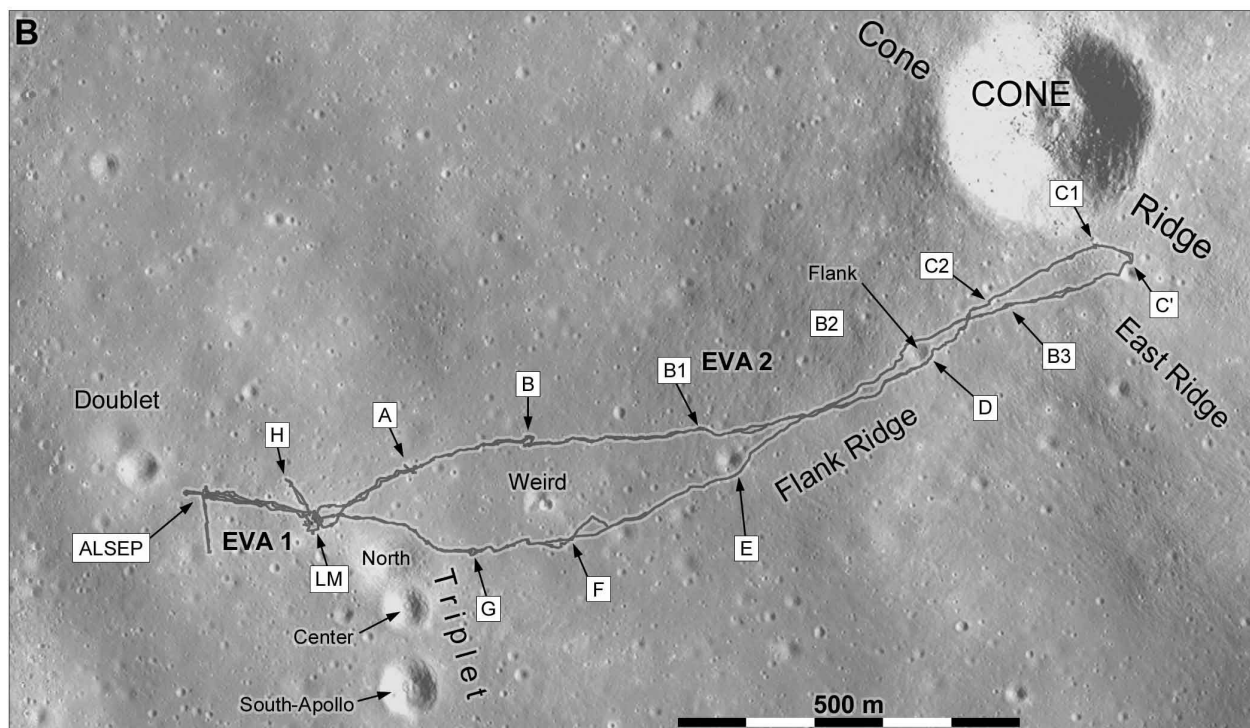
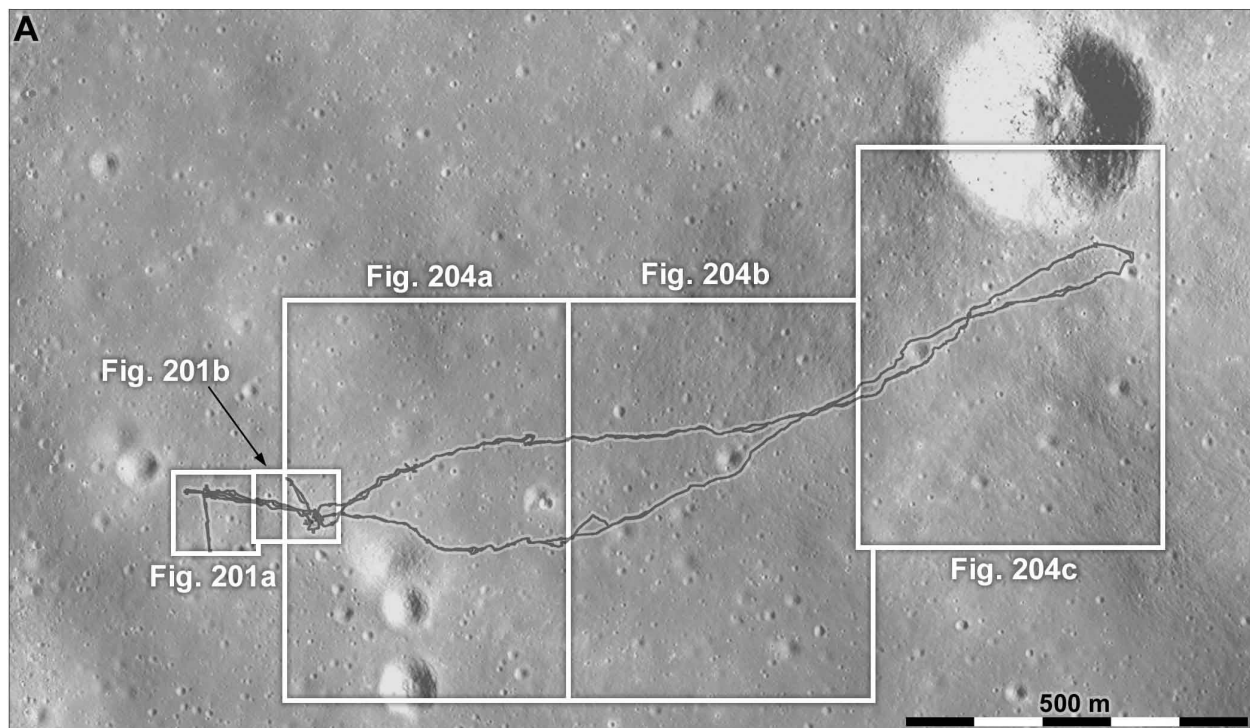


Figure 200. Apollo 14 traverses. A: traverse map and index to detailed maps in Figures 194 and 195. B: traverse map with local names and science station locations. The background is LRO image M114071006LR.

The different dates of Apollos 13 and 14 required slightly different CSM orbit inclinations, resulting in differing LM approach azimuths and a small adjustment to the landing point itself. Figure 199D is a comparison of the two approaches and landing targets.

Each set of EVA plans includes a visit to a young crater, Cone at Site 1, Star at Site 2 and Sunrise at Site 3. At this crater the crew would take two panoramas for good stereoscopic viewing of the opposite crater wall. At Cone crater these would be taken from two stations about 100 m apart. They would roll a rock down the crater slope and observe its motion. They would also attempt a communication experiment by standing behind a boulder large enough to block them from the LM, to test radio restrictions. The activity at Cone crater in these plans was moved to the east compared with Apollo 13 (Figure 171A) to give better viewing of the sunlit crater wall.

Rosenblum (1970) suggested changes to Apollo 14 EVAs to test communications limits and the attenuation of radio signals by topography. Two EVA changes were suggested based on the old Apollo 13 EVA map (Figure 171A). On EVA 1 an astronaut could descend into Star crater, where the radio link may be blocked, loop around it and return. On EVA 2, after visiting Cone crater one or both astronauts could descend Cone Ridge to the south and loop back by one of several routes, allowing the high ground near Flank crater to block communications. The idea of standing behind a boulder was a less risky version of one of these scenarios. This was not attempted during the mission.

The Apollo 14 ALSEP (Figures 203, 211A), deployed during EVA 1, differed from the planned Apollo 13 ALSEP (Figure 171D). Some elements were repeated: the Central Station (common to all ALSEPs), a Passive Seismic Experiment (PSE), and a Charged Particle Lunar Environment Experiment (CPLEE). The Cold Cathode Ion Gauge (CCIG) was deployed with a Suprathermal Ion Detector Experiment (SIDE) as on Apollo 12 rather than alone as on Apollo 13.

The heat flow experiment was replaced with a complex Active Seismic Experiment. Three geophones (small seismometers) were arrayed along a 100 metre long cable, roughly equally spaced (Figure 201A, 203). A hand-held 'thumper' provided a seismic signal at different locations along the array. A second part of the experiment was a small mortar package designed to fire four small grenades to different distances (about 150, 300, 1000 and 1600 m, all towards the northwest across the valley containing the landing site, after the astronauts had left the surface). Each grenade would provide a signal for the PSE and geophones. Concerns about damage to other ALSEP equipment resulted in a decision not to use the mortars. ALSEP layout here is schematic. Pre-flight diagrams differ from this in some details. SIDE is about 20 m from the Central Station, LRRR about 30 m away. The remaining items are within 3 m of the Station.

The activities around the LM during EVA 1 (Figure 202) included setting up the flag, the Solar Wind Collector (SWC), the S-band antenna and the TV camera. The TV was initially mounted on the Descent Stage to view the astronauts' first steps on the surface. Later it was moved to a tripod at the TV1 position to view the flag and other equipment set-up, then to TV2 to monitor the ALSEP offloading, and finally to TV3 to follow ALSEP deployment. At the end of EVA 1 it was returned to TV1, where it remained for the beginning and end of EVA 2. During the traverse to Cone Crater the camera was pointed slightly north of Cone (TV4) (NASA, 1971c).

Shepard brought the LM down between Triplet and Doublet craters, about 70 m east of the planned landing point. After landing the descent stage systems were shut down and made safe to avoid contaminating the area with escaping fuel, and the flight computer was prepared for an emergency liftoff if it should be needed. The crew described the undulating terrain for the geologists on Earth and photographed the scene through the two LM windows (Figure 207A), finding it difficult to match the small craters they were seeing with the maps they carried in the LM.

After a brief lunch break the crew prepared to leave the cabin for EVA 1, temporarily perplexed by a communication problem in Shepard's suit. When that was resolved the preparations continued as intended, following a detailed checklist. Eventually the cabin was depressurized and EVA 1 began at 4:42 UT with the opening of the hatch, which was always a difficult operation in the cramped cabin. Shepard backed out of the hatch and onto the ladder, and Mitchell passed him a jettison bag containing items no longer needed which Shepard dropped onto the ground and later pushed under the LM. They hooked up the lanyard which would be used to transfer items to and from the surface, deployed the MESA with the TV camera, and Mitchell turned the camera on so viewers on Earth could see Shepard descend the ladder.

Shepard stepped out onto the surface, saying "... it's been a long way, but we're here", and proceeded to familiarize himself with the surface, the lunar gravity and his balance, and to describe his surroundings to listeners on Earth. He adjusted the MESA angle and took out the Mobile Equipment Transporter (MET), a small wheeled cart to help carry equipment and samples during their traverses. It was placed initially on a footpad, still wrapped in a thermal blanket. Meanwhile Mitchell left the cabin, climbed down the ladder and tested his ability to jump back up onto the lower rung, something which they could not practice properly on Earth.

The TV camera was to be set up at a distance to monitor activities near the LM, and to avoid damaging it by pointing it at the Sun as on Apollo 12, Shepard put a lens cover on the camera. As he carried it out to a position about 20 m north of the LM (Figure 202), Mitchell collected a contingency sample of regolith in case an emergency departure was necessary. The sample site was near a crater about 10 m northwest of the LM (Figure 202). He then returned to work on the MESA as Shepard positioned the TV camera on its tripod, pointed it at the LM and returned to the LM to set up the large S-band radio antenna. Mitchell deployed the Swiss SWC experiment about 20 m southwest of the LM (Figure 202) and then removed the LRRR package from the MESA and set it on the footpad below the ladder until it was needed. Shepard set up the antenna and Mitchell helped run the cable out to it.

When the antenna was aligned with Earth Mitchell climbed back into the LM to switch communications through it rather than through the LM systems. While he was there Shepard passed the contingency sample and other items up to him on the lanyard and Mitchell returned it with cameras and film for the EVAs. He climbed down, jumping out from the ladder to avoid touching the LRRR on the footpad. The next step was to set up the US flag in view of the TV camera, west of the S-band antenna and northwest of the LM. The two astronauts took pictures of each other standing beside it, following which Mitchell turned the flag to face the TV camera, walked over to the camera and panned it around the horizon to show the surrounding scenery to viewers on Earth. He avoided looking to the east where the Sun was still low in the sky. He described the scene, including a set of 4 small craters he called the 'quadruplet craters' just west of the LM (Figures 201, 202, 208). They already had Doublet and Triplet, but the reference to 'quadruplet' was spontaneous and not shown on the mission maps. Meanwhile Shepard moved to three positions around the LM to take photographic panoramas to document the landing site.

After the photography was completed the Director of Flight Crew Operations, astronaut Deke Slayton, relayed a message of congratulations from President Nixon, who was watching the EVA from the White House. The crew then deployed the MET, which had two wheels with inflated rubber tires, the only such tires ever used on the Moon. Shepard then moved to the TV camera, covered the lens with its cap and carried the camera and tripod to a position east of the LM to monitor the ALSEP offload operations. It was set up pointing to the west, giving a good view of the LM. The ALSEP components were packaged in two bundles and stored in the Surface Equipment bay (SEQ) on the southeast side of the LM. Mitchell opened the SEQ bay door, allowing Shepard to remove the first ALSEP package, which was pulled out on a boom and lowered to the ground suspended on two ribbons. Mitchell then did the same for the second package. One discarded ribbon swung like a pendulum for more than a minute and video of the motion has since been used as a lesson in pendulum physics.

Shepard moved the booms out of the way as Mitchell removed a tool carrier like that used on Apollo 12 from the second ALSEP package and mounted it on the MET. Shepard then removed two tools from the ALSEP packages and positioned the second package to fuel the RTG. The nuclear power source was mounted outside the LM to the left of the SEQ bay, and its container was lowered by Mitchell to extract the hot fuel capsule. He took a tool from the ALSEP package, opened the lid of the container, extracted the fuel capsule with a tool and placed it in the RTG on the second ALSEP package. Small craters restricted movements during these delicate operations more than anticipated during training, but everything was completed successfully. Now the ALSEP Central Station antenna, which Shepard had attached to the first ALSEP package, was used to join the two packages together, forming the 'barbell' configuration needed to carry it to the deployment site.

Shepard closed the SEQ bay door and moved to the camera to carry it to its ALSEP monitoring position. He covered the lens again and carried the camera and tripod to a point 15 m north of the LM, set it up and pointed it at the LM. This was a colour camera, but a backup black and white camera like that used on Apollo 11 was also available, and Shepard now stowed it on the LM's north footpad to keep it out of the way. The crew loaded cameras, sample containers and other equipment from the MESA on the northwest side of the LM onto the MET. One of these items was the Lunar Surface Close-up Camera (LSCC), used for the last time on Apollo 14. Shepard

returned to the camera and pointed it to the west, zoomed in to view the expected ALSEP deployment location near Doublet Crater. The terrain was more undulating than anticipated and a level site was needed for the ALSEP, but this area appeared suitable from a distance.

Mitchell carried the ALSEP barbell out to the deployment site while Shepard pulled the MET and carried the LRRR. They walked out to the west, but Mitchell had some difficulty with the heavy ALSEP and had to set it down soon after setting out. The weights at each end of the carrying bar bounced as he moved, making balance difficult. Bruce McCandless, the CapCom (capsule communicator, the person responsible for all direct communication with the crew), back in Houston, guided the crew to keep them within the field of view of the camera. They walked around the north side of a crater which blocked their path, Shepard moving out of the camera's view for a moment, and then crossed a large shallow depression. Mitchell set the barbell down again as they looked for a level area for deployment, then headed for a higher region just beyond the depression, and up on that ridge they both looked at their map to try to locate themselves.

Satisfied that this was a suitable area, they moved another 10 m west and north to the best location for the Central Station, then south a few metres for better TV visibility, and set everything down. The MET was set up 10 m south of the Central Station with an automated video camera documenting the activities. This location was about 200 m west of the LM, twice as far as planned because the expected location was in the large depression and largely hidden from the TV camera. Mitchell worked on the Central Station while Shepard removed a subpallet from the package and set it out 3 m northeast of the Station. This held the SIDE and CCIG experiments, bolted to the subpallet, and the bolt housings were full of dust. The two astronauts had to tip the subpallet over and shake the dust out before the bolts could be freed, but still had considerable difficulty removing the SIDE for deployment. Then the video camera film magazine had to be replaced.

Mitchell now removed the thumper part of the Active Seismic Experiment (ASE) from an ALSEP package and set it on the MET while Shepard positioned the base of the PSE instrument 3 m north of the Central Station. Mitchell threw a piece of packing material from the thumper away to the south, impressed with how far it travelled. Next, he placed the ASE mortar pack 3 m northwest of the Station as Shepard continued with the seismometer deployment, and then removed the CPLEE instrument. Shepard's foot caught one of the cables and pulled the Central Station out of alignment slightly, so they had to reposition it. The crew had fallen nearly 40 minutes behind schedule, and now Mission Control allowed them a 30 minute EVA extension.

Shepard was levelling the Central Station prior to releasing bolts to deploy it fully, while Mitchell set out the CPLEE. The mortar pack had to be aligned so its grenades would not fall into craters or hit a ridge, if possible, and Mitchell now confirmed that the pointing was satisfactory. Then he carried the SIDE instrument out to the southeast. It was intended to go northeast of the Station but the topography seemed to favour the southeast. As with Apollo 12, the stiff cable connecting the CCIG to the SIDE caused problems during deployment. The next item was a penetrometer experiment, an instrument designed to be pushed into the regolith to measure its strength. Mitchell used it at two positions about 8 m south of the RTG. Meanwhile Shepard was setting up the Central Station antenna.

Mitchell's next task was to set out the geophone line and use the thumper alongside it to generate seismic signals for the geophones. The line was fixed into the ground by an anchor peg so it could be pulled straight without disturbing the Central Station. Then he walked to the northwest about 8 m to look over the anchor and find a horizon marker to guide his path with the geophone line. The topography made this harder than expected and the line was set out running nearly north-south rather than northwest-southeast as planned. He set out the first geophone (Figure 203) and pressed it into the regolith with his boot to make a solid connection, then moved south again. Shepard guided him briefly, then started to deploy the LRRR. He was reminded by McCandless that a thermal blanket had to be placed around the PSE, and did so. Mitchell had more trouble getting the second geophone to stay in the ground. He moved south, deployed the third and then noticed that a flag at the second geophone had tipped over.

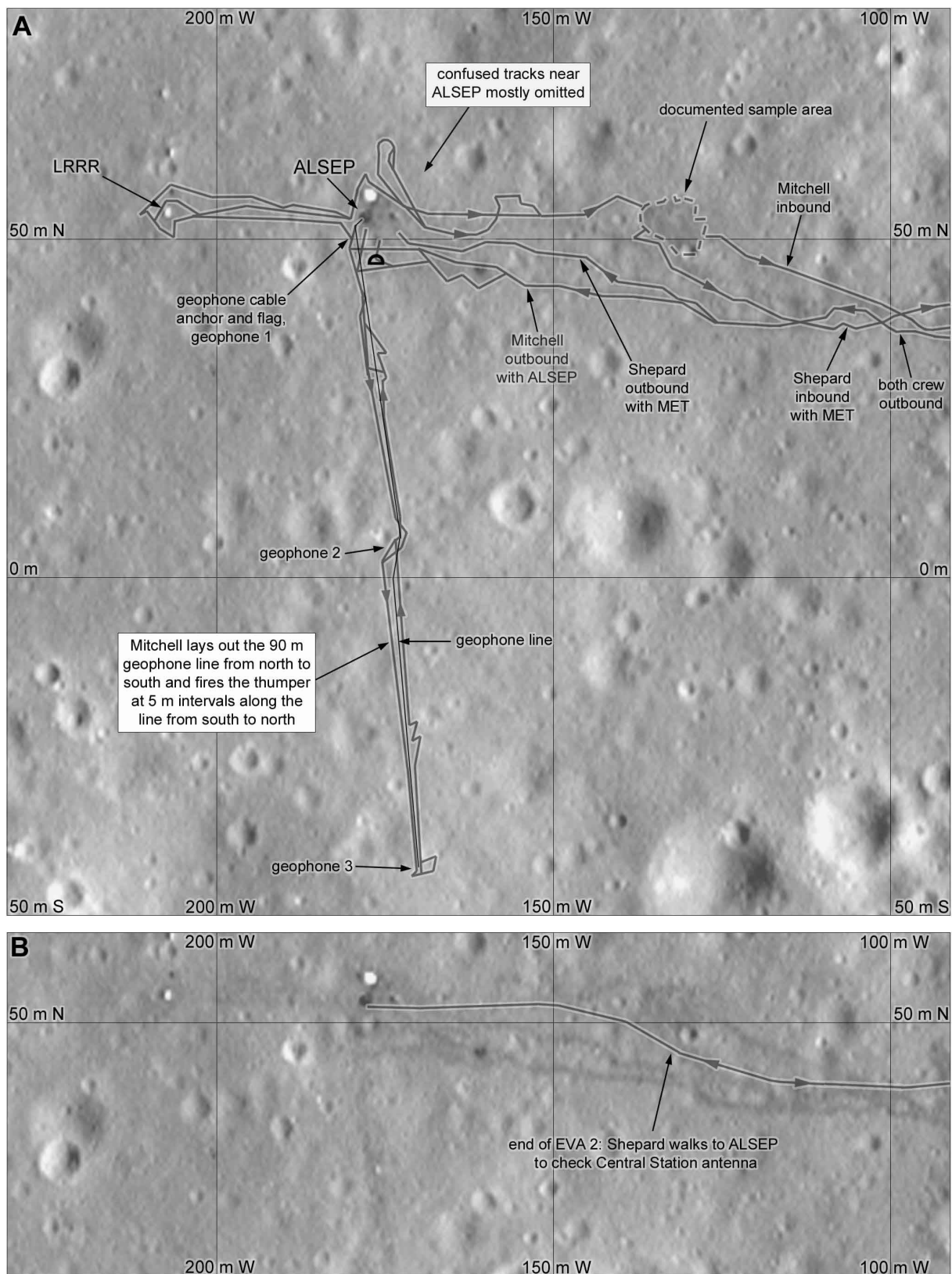
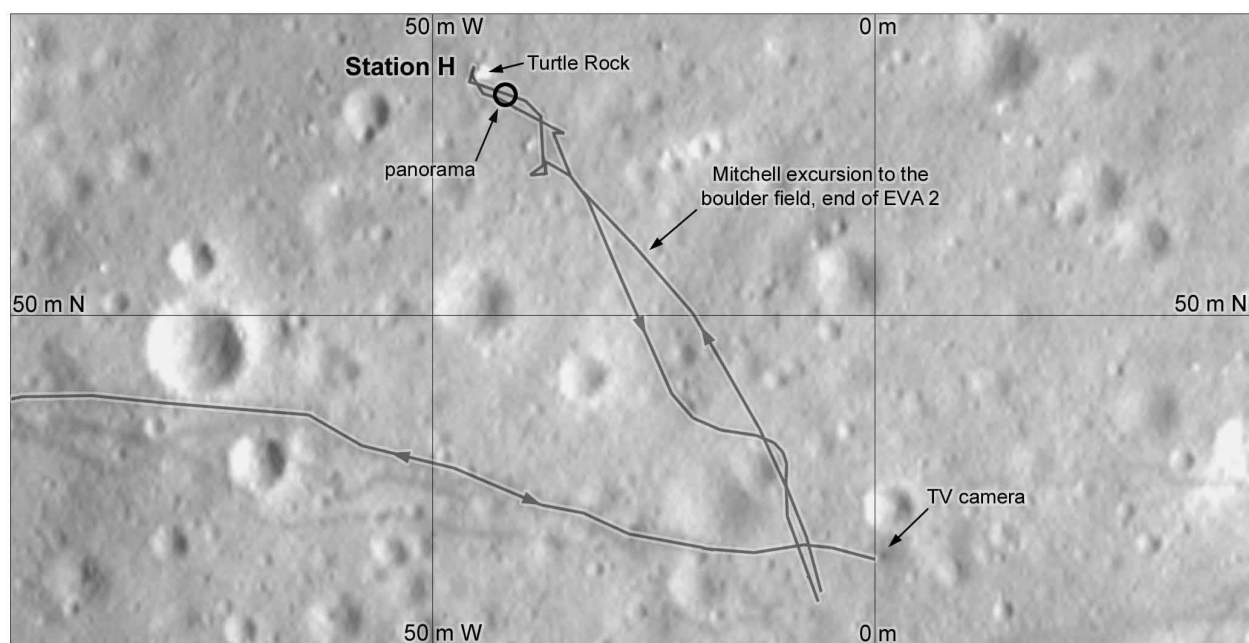
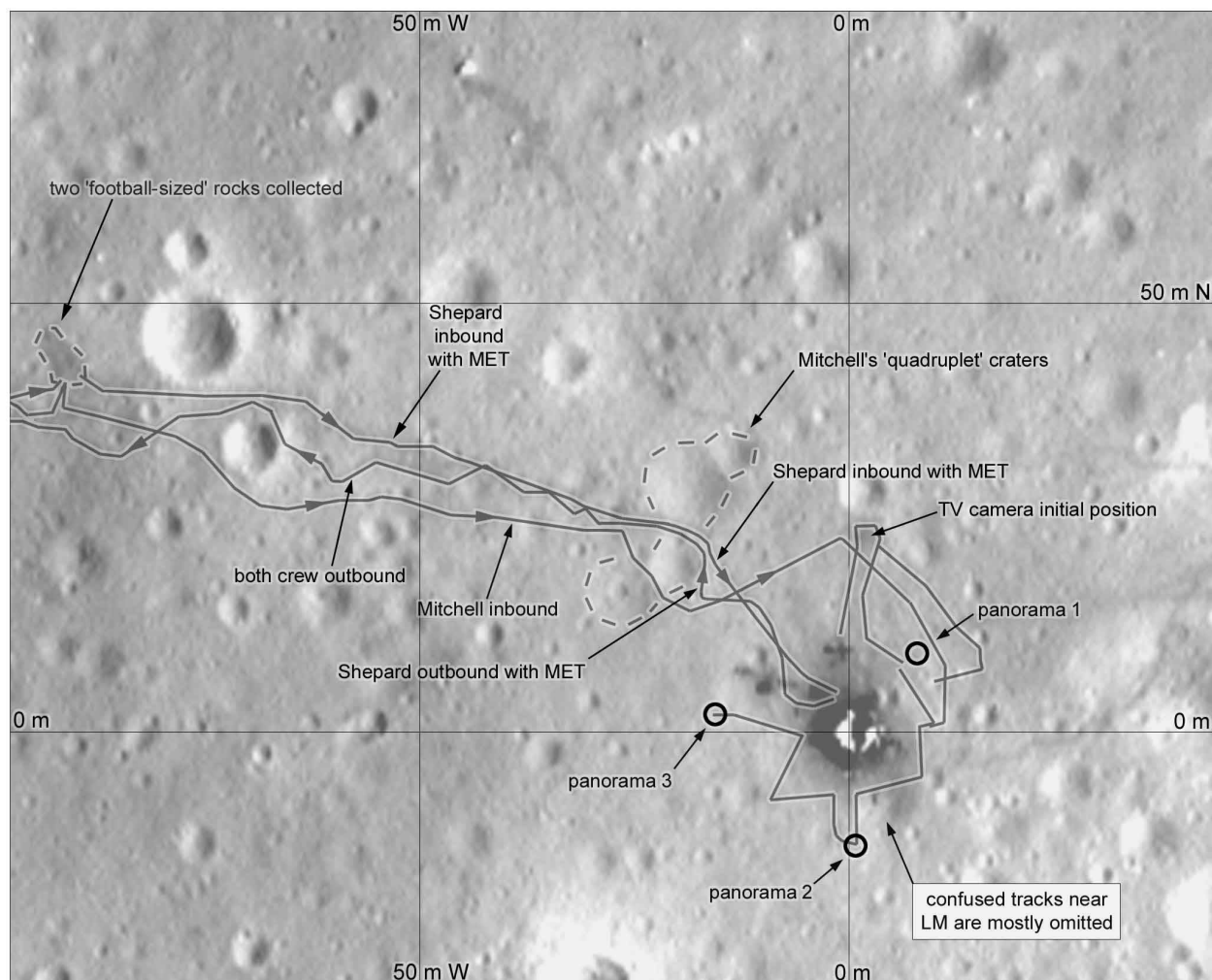


Figure 201 (across both pages). Apollo 14 EVAs. A (both pages): EVA 1 activities. B (both pages): EVA 2 activities west of the LM.



Shepard now took the LRRR out 30 m to the west and set it on the ground, orienting it to reflect laser pulses back to Earth and removing a cover. Mitchell was briefly tangled in his geophone line, but was soon ready for a calibration firing of the thumper, for which both astronauts had to stand still for 20 seconds to allow vibrations to die down. The thumper failed to fire for the first calibration, and while they considered this Shepard moved back to the ALSEP to take documentation photographs of it. A second thumper firing took place as expected. Shepard replaced the film magazine in the video camera again, and Mitchell made a third thumper firing. The intention was to fire the thumper at 5 m intervals along the 100 m geophone line, though some firings failed, mostly in the first half of the experiment. Altogether, only 13 of 21 possible firings were successfully completed, though 3 were skipped altogether. The thumper provided a seismic signal which was reflected from boundaries between layers of material of different density to indicate the subsurface structure. Results showed that the Fra Mauro Formation (Imbrium basin ejecta) was 45 to 85 m thick here, and that an 8.5 m deep regolith had formed over it. The mortar with its larger charges and greater spacing, up to 1600 m, would have probed to greater depths, but it was never activated because of concerns it might damage other ALSEP equipment.

When Mitchell got close to the second geophone he noticed that the entire device, and not just its flag, had slipped out of the ground and was on its side. It was still returning some results despite this, but he redeployed it in the ground and then resumed firing the thumper. At about this point Shepard took a photograph of Mitchell with the thumper, about half way down the geophone line. At the last firing point both astronauts were directed to stand still again for a calibration shot. The astronauts were now running about 30 minutes behind schedule, but a half hour extension of the EVA was granted. The EVA plan allowed for a geology traverse around Doublet Crater if time permitted, followed by arming the mortar and returning to the LM, but Houston now wanted them back at the LM in only 20 minutes. The crew were directed to abandon the Doublet traverse, arm the mortar and return, picking up some samples along the way.

Mitchell armed the mortar while Shepard walked to the MET and set off with it, walking back towards the LM and looking for a place to collect a 'comprehensive sample', larger than the contingency sample. He chose a spot about a third of the way back to the LM and north of their outbound footprints, and used one of the tools to draw a circle roughly 3 m across in the regolith, within which they could collect small rocks and finer material. As he drew the circle he walked outside it, trying not to disturb the sample area. Mitchell soon ran over to help collect the samples. They used tongs to pick up small rocks and a scoop for surface layers of fine undisturbed regolith. They tried to collect numerous 'walnut-sized' rocks by hand (later missions had a rake to make this easier), big enough to reveal cosmic ray effects and numerous enough that occasional exotic rocks might be included. As Mitchell collected the last scoops, Shepard walked further east to find a roughly football-sized rock (about 25 cm diameter). He found two slightly smaller rocks and collected both of them. Then with only minutes to spare they returned to the LM to end the EVA. As he passed the TV camera, Mitchell turned it to face the LM again.

Both astronauts transferred their samples, cameras and film to the MESA table. They put samples into containers for return to Earth, filling one of them with additional material from near the LM. Shepard ran over to the TV camera, after getting tangled in the cable briefly, and prepared it for the break between EVAs. Then they worked together to try to brush some of the clinging dust off each other, to minimize the amount carried back into the LM. That had been a problem on Apollo 12, so this crew carried a brush for the purpose. They had to avoid the S-band antenna cable and the TV cable again, a constant problem for Apollo crews. Mitchell climbed up the ladder and Shepard passed a sample box up to him. They took the time to ask after Roosa, orbiting the CSM, and were told he had passed over them only about 10 minutes earlier, and had been able to see the LM on the surface, but he was having problems operating the HYCON camera intended to photograph future landing sites (Figure 215).

The MET had been left in the shadow of the mesh-covered S-band antenna, but this produced only a weak shadow. Shepard now covered the MET with the discarded S-band antenna cover to keep it cooler, and used the lanyard to pull a bag of samples and cameras up to the cabin. Then he climbed up the ladder and helped get the bag and sample box inside the cabin before entering himself. Next they repressurized the cabin, prepared the PLSS units for EVA 2, and found time for a hasty meal. The sample containers were weighed to help calculate the return mass for takeoff, and the crew answered a few questions from Houston about their observations and thoughts for EVA 2. Then the two astronauts strung up their two hammocks and began their sleep period.

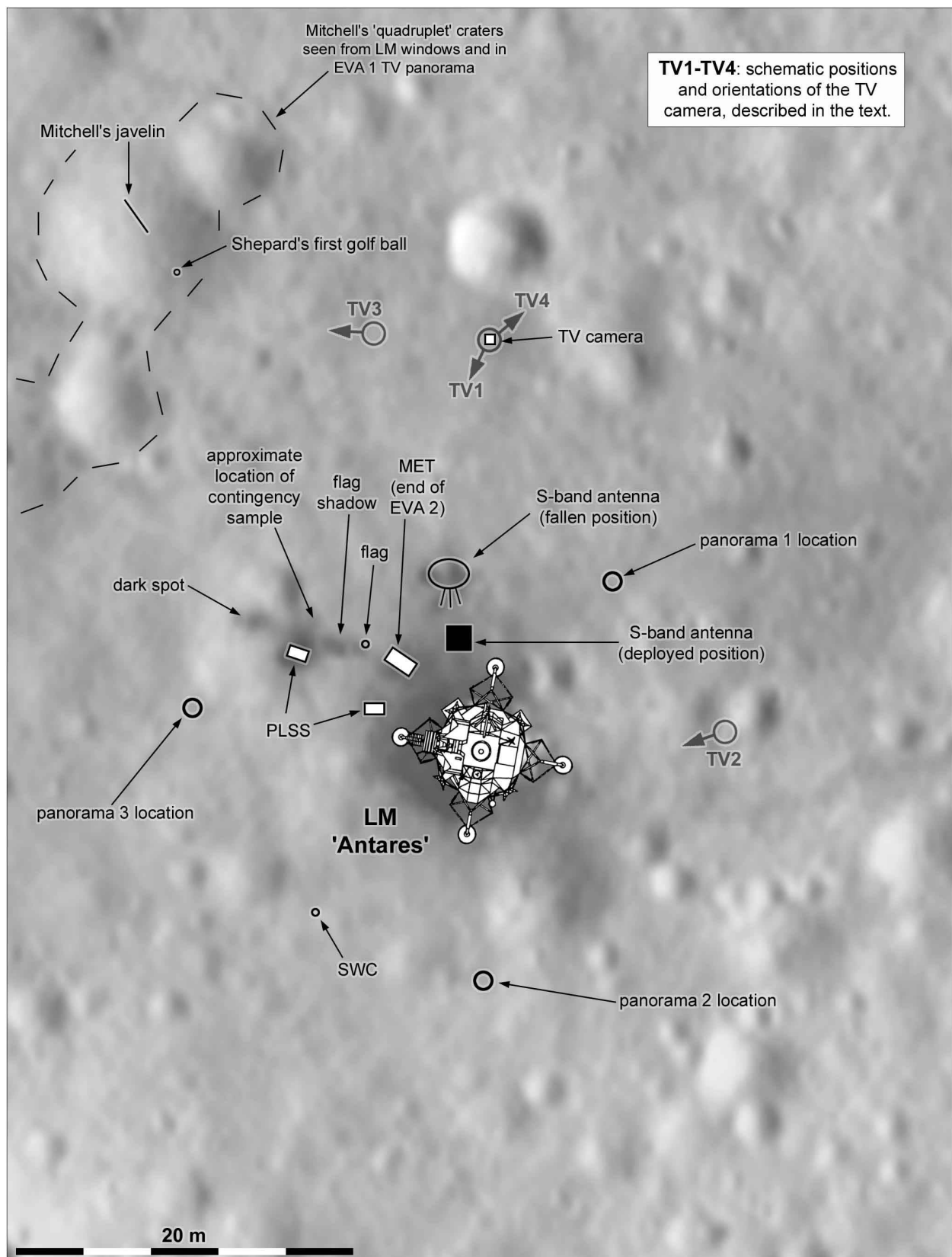


Figure 202. Apollo 14 LM area.

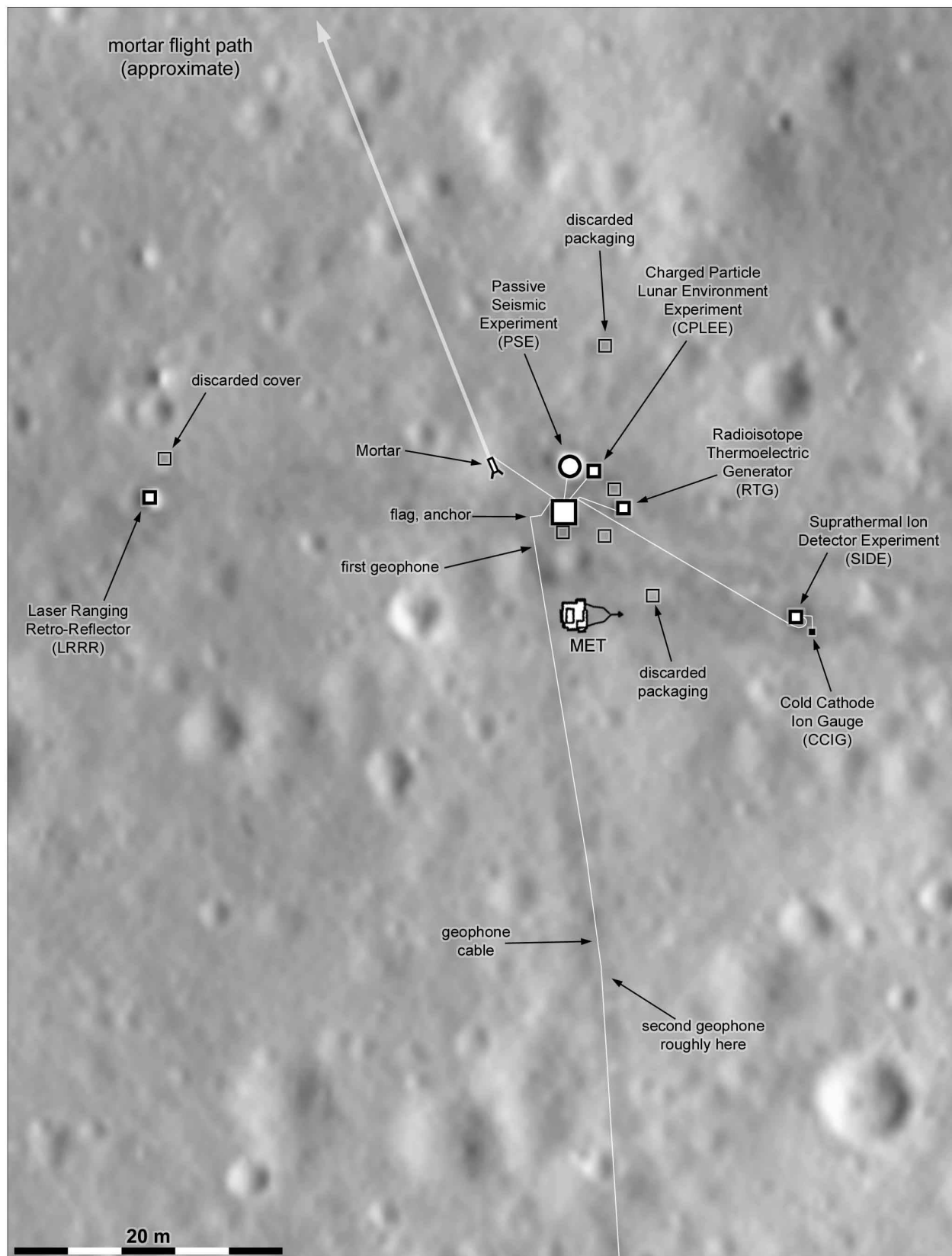


Figure 203. Apollo 14 ALSEP deployment area.

EVA 1 had lasted 4.8 hours and covered a distance of roughly 1 km. Figure 201A shows the EVA activities. Tracks made by the crew are identified where possible using images taken on the surface or from the LM windows. Figure 201B shows activities in the same area during EVA 2.

6.5 hours later the astronauts were awake and ready to start work again. EVA 2 began at 8:11 UT on 6 February, 2.5 hours earlier than planned at the crew's request. They checked the LM and suit systems with Houston and prepared the LM computer for liftoff. Gene Cernan, the backup crew Commander in Houston, stepped in briefly and requested that an astronaut return to the ALSEP at the end of EVA 2 to check the Central Station antenna alignment. The ALSEP signal was weaker than expected. Shepard said he would prefer to do that at the start of the EVA, but he was overruled. A few other changes were made to the EVA plan to save time, primarily taking less time to document the locations of some samples, and then the complex process of preparing the suits for EVA began. When the cabin was depressurized the escaping gas blew the flag, previously face-on to the TV camera, so it pointed at the camera. The CCIG at the ALSEP also detected the escaping gas.

Shepard climbed out of the hatch first, dropped another jettison bag of unwanted items, and moved down the ladder to the surface. The Equipment Transfer Bag was pulled down on the lanyard, and then Mitchell stepped down the ladder. Shepard said that it was a beautiful day at Fra Mauro Base, a name recalling the use of Tranquillity Base at Apollo 11 but never used officially for the Apollo 14 site. He helped Mitchell deploy his suit antenna and fix a stuck visor on his helmet, and they stowed items on the MET for the EVA. Shepard pulled the MET around the LM, taking care to avoid the various cables on the ground, and Mitchell joined him at the SEQ bay to retrieve the Lunar Portable Magnetometer (LPM) which they would take with them on the EVA. Mitchell set off, pulling the MET, while Shepard walked to the TV camera and pointed it towards Cone Crater. It would show the initial stages of their departure on the 1200 m walk to Cone, but no more until they returned. The Sun was still fairly low in the east, not far from Cone, so Shepard wanted to move the camera into the LM shadow to block the Sun and improve the picture. To save time it was just pointed carefully away from the Sun while still showing part of the ridge.

Shepard ran out to catch up with Mitchell, who then stopped to check his position on the map they carried, an annotated Lunar Orbiter photomap. While he did so Shepard used the LSCC to image the MET tracks and his footprint. Then he pulled the MET while Mitchell navigated with the map, pointing out North Triplet and Weird craters as they went. They passed just south of a 'kind of doublet crater' (Figure 204) (not Doublet, but a small pair of craters) and the geologists in Houston asked them if the rocks they were seeing were arranged like rays around Cone Crater. Shepard said they were not. The crew were uncertain of their location now and chose a Station A stop only about half as far from the LM as the pre-flight plan intended (Figures 199 and 204).

Describing the site (Figure 205), Shepard noted more small pebbles and larger rocks than near the LM, and Mitchell observed a texture resembling raindrop pits on the dusty surface, presumably made by scattered ejecta. Shepard collected samples while Mitchell deployed the magnetometer on its tripod. Each time it was used measurements were made 3 times with the instrument in different orientations, and each time the astronaut had to return to the MET to read the measurement from the meter, allowing 60 seconds for the instrument to stabilize. A cable connected the instrument to the MET. Mitchell then photographed the LPM to locate it for post-mission analysis. He took the three readings, rotating the LPM between them, while Shepard collected samples and took LSCC images of the so-called raindrop regolith texture, a footprint, and a fillet or bank of regolith around a rock. Shepard then collected a double core tube, far enough away from the local small craters that he was sampling Cone Crater ejecta rather than local post-Cone ejecta. He hammered the core tube into the ground, easily at first but with difficulty lower down. Mitchell rolled up the LPM cable, experiencing considerable difficulty with it, and photographed a panorama of Station A to characterize it and locate it unambiguously. He then collected a rock sample and took photographs before and after sampling. The rock was cracked and broke into several pieces as he worked with it.

The astronauts now headed out, eastwards from Station A, Shepard leading with the MET while Mitchell finished work with the broken rock. The route took them down into a small hollow and up the other side, gradually climbing the slope up towards Cone. Both astronauts had trouble finding their locations on their map and stopped briefly to consult it, disagreeing about their positions. They chose a 'Station B' location close to the originally planned Station A, in an area with more rocks than they had seen elsewhere, and Shepard took a panorama while Mitchell described the area for the listeners on Earth. Some of the rocks may have been arranged in 'rays', or linear clusters extending

outwards from Cone. By now they were no longer visible in the TV camera image. Shepard collected a grab sample (taken quickly without detailed documentation) from the western rim of the crater here (Figure 205) which he referred to as 'Bravo Crater' for its location at Station B.

Mitchell pulled the MET up the undulating slope from Station B as Shepard looked for identifiable craters. As they passed a 20 m diameter fresh crater he stopped to pick up a small rock sample from its rim. After this the slope steepened and the MET wobbled and bounced as it was pulled along, nearly tipping from time to time. If the astronauts found it difficult to pull the MET uphill they could drop it off along the route and retrieve it on the return, but they didn't feel it necessary. They passed a rock spattered with impact glass, rock melted by the heat of an impact and still molten as it fell on the rock. They paused to rest, and Shepard took the MET on from here as they walked up to a crater near the original Station B location. The two astronauts thought they were further uphill than they really were, near Flank (Figures 204, 205) and stopped to check their location. After the mission this site was referred to as Station B1. Shepard took a panorama while Mitchell consulted the map, and looked back at the LM he noted that it was distinctly tilted, sitting on the uneven ground. As they moved on he thought he could see Flank nearby, and Shepard noted a small crater on the southern rim of this crater which seemed to confirm the identification, but this was a coincidence. Both this crater which would become Station E on the return journey and Flank had small craters in similar locations, though Flank's was more on its floor.

Mitchell took over pulling the MET now, but as the slope steepened again Shepard, behind the MET, lifted it and they carried it between them. The next rest stop was near a large partly buried rock later called Big Rock, at Station B2, where Shepard used the Apollo Lunar Surface Closeup Camera to take an image of the rock and Mitchell took another panorama (panorama G in Figure 207). After the mission these panoramas provided unambiguous station locations. Shepard pulled the MET again after Station B2, but soon they had to stop for another brief rest and Mitchell took another turn with the MET. They had been climbing a spur of Cone Crater Ridge referred to as Flank Ridge, and now could look over a shallow depression to a more distant part of Cone Crater Ridge which is called East Ridge on Figure 200B. Among the features which were hard to locate was the rim of Cone Crater, the main goal of the EVA, and they remained unsure of its exact location.

They continued climbing the increasingly rocky slope, informally referred to as 'Flank Ridge', towards the rim of Cone, but at Station B3 they again stopped to rest at the suggestion of the Flight Surgeon in Houston, who was monitoring their heart rates and breathing. Shepard and Mitchell now disagreed about where they should stop and sample the Cone Crater ejecta. Shepard wanted to stop where they were, Mitchell wanted to continue to the crater rim. The mission managers now granted them an extra 30 minutes of EVA time, so they decided to go a little further, thinking that East Ridge was the rim of Cone Crater. In fact they were walking parallel to the rim at this point. They noted that their tracks were revealing a light gray regolith layer just under the surface, and Mitchell took a panorama here at Station B3 among a cluster of small craters and boulders with prominent fillets. Then they moved eastwards again, Shepard with the MET and Mitchell helping with it in difficult spots. Finally, seeing a crater on East Ridge, Mitchell realized they were south rather than west of the rim of Cone Crater and they could reach the true rim from here. They skirted the crater, Mitchell pulling the MET again, and prepared to work at this site, referred to as C-prime (C'), about 100 m south of the original Station C on the crater rim. This was about 1500 m from the LM.

Shepard began work at C' with a panorama. To save some time a polarimetric experiment, involving photographs taken in different directions with a special lens filter, was cancelled. Shepard noted that the regolith had a lighter layer under a darker surface. Mitchell collected samples and deployed the magnetometer for the last time, while Shepard tried to collect a regolith core by hammering a core tube into the ground. The granular regolith fell out when it was pulled up, so he abandoned the core and scooped soil into bags, sampling the surface and underlying layers. Mitchell read the Magnetometer readings, and then unhooked the magnetometer from the MET and left the instrument at Station C'. He did not photograph the magnetometer so the exact location of the reading is uncertain. Flashes of light reflected off two items here are visible in some LRO images, possibly parts of the Magnetometer ribbon or discarded sample bags (Figure 205).

They then moved a short distance northwest to a cluster of very large rocks, 3 or 4 metres across, collectively known as White Rocks, not realizing they were almost at the rim of Cone. This stop is referred to as Station C1 and the largest rock is Saddle Rock (Figures 206, 207). The unusual geometry of Cone was misleading them. It had formed on the side of the ridge, not its summit and its rim was much lower on the north side than here on the south rim, so

even though C' was higher than C1 there was no view into Cone from any of the stops in this area. They photographed the boulder field and Mitchell collected samples, using a geologist's hammer to chip pieces off the large rocks. Shepard picked up samples, including a 'football-sized' rock which was nicknamed Big Bertha after the mission. After a very short stay here they headed back down the ridge towards Weird crater. The better viewing and illumination conditions made choosing their route easier on the way down, and they could move much faster, slowed only by the awkward MET Shepard was still pulling. Mitchell watched to check that nothing fell off it as it bounced along.

One goal discussed prior to the mission had been to investigate the blocking of radio signals by obstacles (Rosenblum 1970). If an astronaut stood beside a large boulder which blocked a direct radio link to the LM, would communications be lost, or would the signal reflect off nearby features and still be detected? The question was raised now by Fred Haise, the CapCom in Houston, but it was too late. The boulders at Station C1 were the only rocks large enough and the astronauts had already left them behind. They stopped briefly to locate Weird crater, distinctive for a large rock nearby and its unusual shape, a composite of three impacts. Shortly after that another brief stop was made at Station C2, very close to B3, to sample a rock with a very distinctive fillet around it (Figure 205).

Two minutes later, at Station D near Flank crater, they stopped again to pick up a rock sample, and about 3 minutes after that they stopped again at Station E. One sample here was a 'soft rock', a regolith breccia made of small particles fused together with impact glass or just by the shock of impact, but very fragile and easily crumbled. Moving on, they approached Weird Rock, the prominent boulder near Weird crater. Here, Shepard ran over to the rock to see if it would block his radio communications. He had to do this as only his radio transmitter communicated directly with the LM (Mitchell's transmitter communicated via Shepard's). The rock was too small for the experiment to work, but Shepard photographed the rock as he passed it.

The next stop was at Station F just south of Weird crater. Shepard began by taking a panorama, which would help to locate the station because the astronauts were not sure exactly where Weird was in the rolling topography. Mitchell quickly collected a sample, and then they moved on towards Triplet and Station G where documented sampling resumed. They were asked to stop about one crater diameter (100 m) east of the northern and larger of the Triplet craters (Figure 204) but stopped slightly closer than that as they approached the crater rim. Mitchell assembled a triple core tube and pushed it into the soft ground as Shepard was digging a trench in a small crater rim nearby (Figure 206). The core tube stopped at one tube depth, apparently hitting a rock, and Mitchell was asked to remove it, save the lower tube with its sample, add a new tube section and try again nearby.

Shepard described the regolith cross-section he was uncovering. Under the surface layer he encountered a layer with impact glass fragments, and below that a lighter layer. The loose material collapsed rather than leaving a clean vertical face, so the layers were mixed, but he collected what he could. Meanwhile Mitchell hammered the core tube down as far as he could, but it did not go down to the third tube as the regolith became much firmer with increasing depth. Then he extracted and stored it. Shepard took a panorama again, and deepened the trench before taking another sample from its floor, to be placed in a special container which preserved it in vacuum for the return to Earth. This was the Special Environmental Container (SESC), and Shepard had trouble with one and discarded it before the second worked properly. Mitchell collected a few other samples nearby, and then it was time to return to the LM.

Shepard and Mitchell now walked eastwards around the northern rim of North Triplet, Mitchell pulling the MET. As it bounced along the SESC fell off, and Shepard, walking behind, retrieved it. They stopped at Station G1 on the crater rim (Figure 204) to collect two partly buried rocks from a small boulder field. They had to hurry now to return to the LM and prepare for liftoff, and again as the MET bounced along another item was lost, this time a core tube. Mitchell was following the MET this time and retrieved the tube. As they arrived at the LM, which Shepard now referred to as 'Fra Mauro Base', they split up, Shepard heading for the ALSEP to check the Central Station antenna pointing while Mitchell quickly collected samples near a group of boulders just north of the LM.

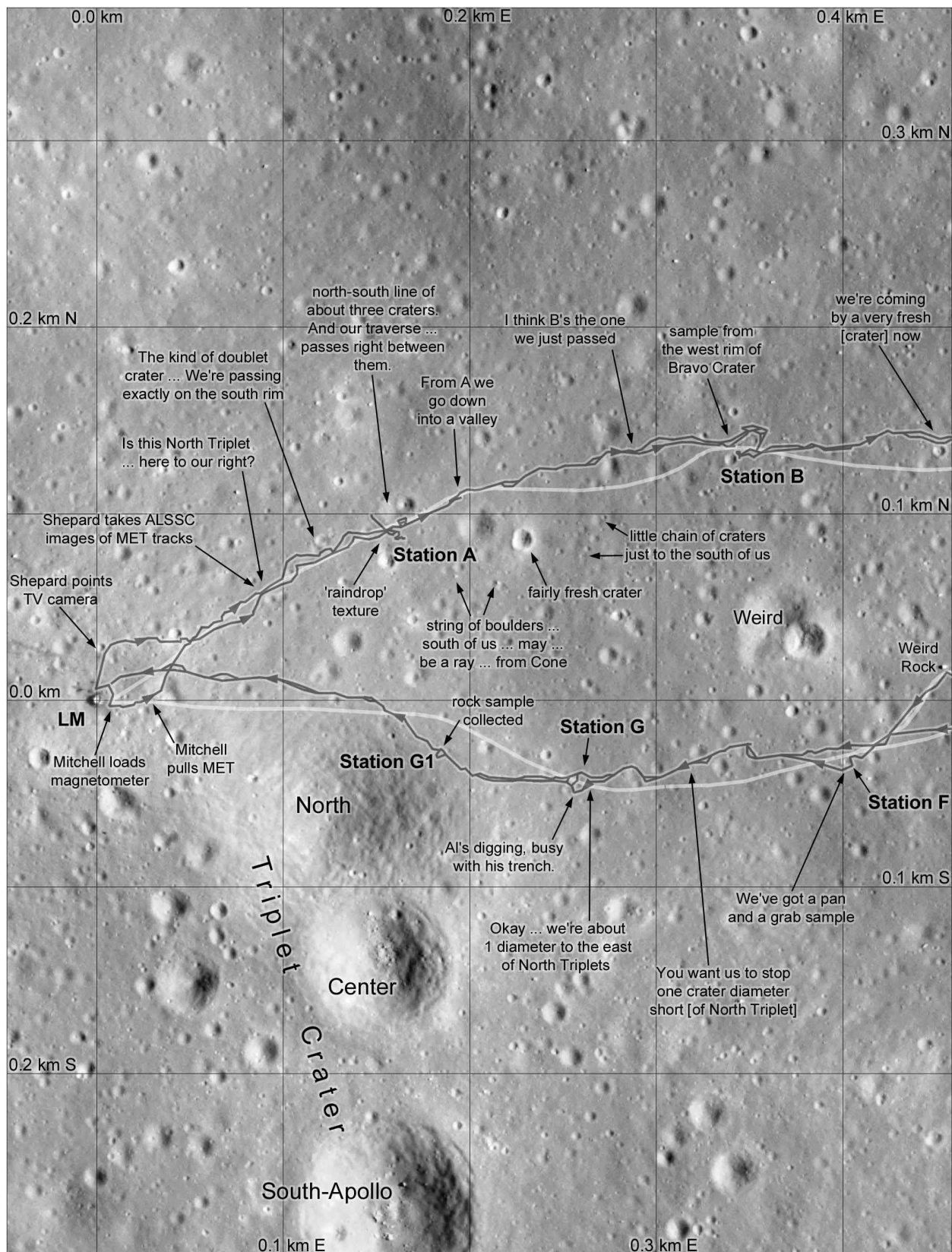


Figure 204. Apollo 14 EVA 2 (across three pages).

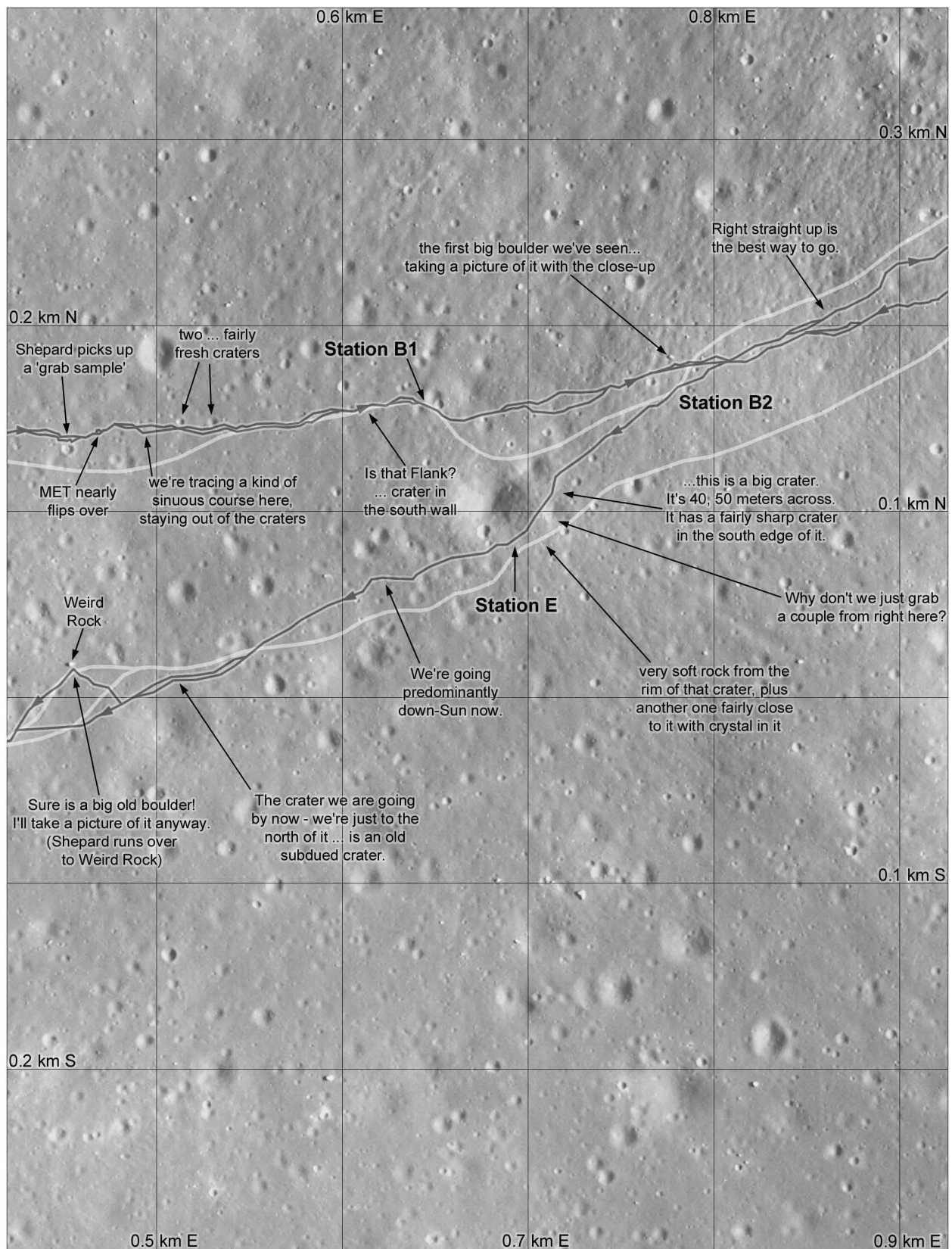


Figure 204. Apollo 14 EVA 2 (continued).

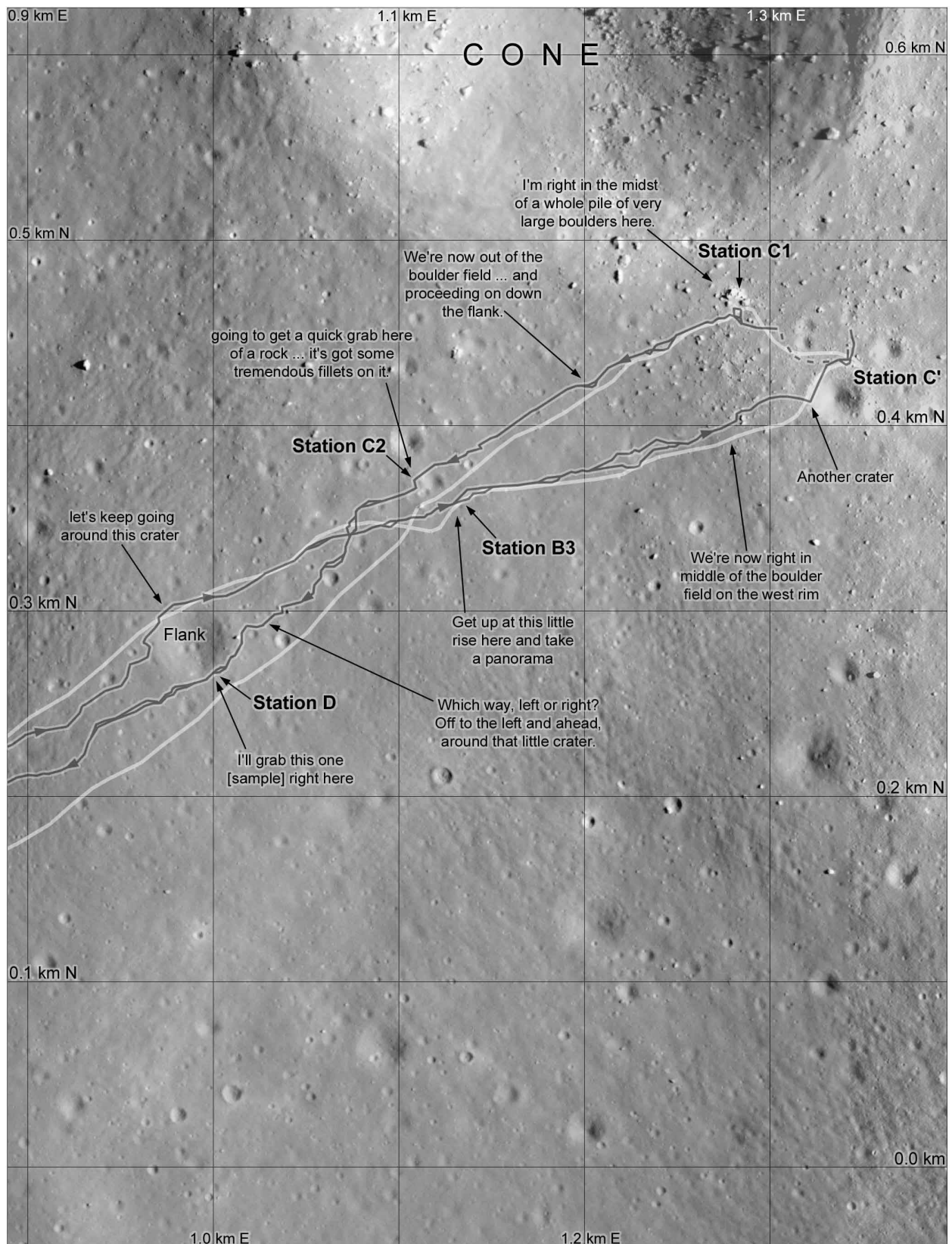


Figure 204 (continued). Apollo 14 EVA 2. Tracks just west of Station C' are very difficult to identify.

At the ALSEP and guided from Houston, Shepard changed the antenna pointing to improve its signal strength. Then he returned to the LM and pointed the TV camera back towards the LM so viewers on Earth could follow the end of the EVA. He also photographed Earth above the LM, and by chance also caught Venus in the same frames, and then took pictures of the Swiss SWC experiment. Mitchell collected several samples at the boulder field, took a panorama and photographed several boulders including one later named Turtle Rock, a large rock on top of which was a smaller one which resembled a turtle. Then he returned to the LM. The MET had been left at the LM so nothing would fall off it and be lost if it was pulled out to the Turtle Rock area, and now Mitchell moved it to the MESA for unloading.

The original plan called for a sample contaminated by rocket exhaust to be collected from under the LM, but this was dropped. The crew started bagging equipment to return to Earth, including Shepard's camera, and Shepard, an avid golfer, took the opportunity to fix a golf club head to the handle used to collect the contingency sample in EVA 1. He had brought two golf balls with him, and now dropped one in front of him, narrating his activities for the television audience. He swung the improvised golf club, single-handed, but missed the ball and hit the ground. A second swing knocked the ball less than a metre, and a third connected properly and sent the ball off to the northwest, where it fell in a crater about 30 m away. Shepard claimed it flew 'miles and miles'. He dropped a second ball and hit it in the same direction, later suggesting it had landed somewhere near the ALSEP. The club head was brought back to Earth and can now be seen at the U.S. Golf Association Hall of Fame in Far Hills, New Jersey.

The astronauts bagged equipment and samples and discarded an unused core tube, and Mitchell rolled up the SWC foil. Shepard had trouble avoiding the TV cable on the ground with his feet and it moved the TV camera as he tried to free himself. This happened several times during the rest of the EVA, culminating in the camera tripod falling over. Any of the rocks were too large to fit in the sealed sample boxes and were placed in bags instead. Mitchell threw the SWC staff away from the LM, like a javelin as Shepard said at the time, and it fell into the same crater where Shepard's first golf ball had landed (Figure 202). As packing concluded, one film magazine was left in its camera mounted on the MET and is still on the Moon. Mitchell then climbed up the ladder to the LM hatch, stamping his feet to shake dust off his boots and legs, and it was now that Shepard became tangled in the TV cable and tipped the camera over. He quickly righted it again and brushed dust off the lens before returning to the LM.

Mitchell had descended from the LM hatch and now climbed up again, ferrying items to the cabin. At one point he stopped half way down the ladder and leaned out to get a glimpse of Earth over the LM. They used the LEC to haul heavy items up to the cabin, and eventually Shepard climbed up with one last bag of rock samples. The cabin was now more crowded with sample containers and bags than the earlier Apollo LMs had been, but the astronauts managed to find room for themselves and close the hatch. The cabin was pressurized again, formally ending EVA 2. It had lasted 4.6 hours and the crew had walked approximately 4 km, collecting a total of 42.3 kg of samples during both EVAs. They were later dated at about 3.85 billion years old. Once the suits were hooked up to LM systems the PLSS backpacks could be removed and discarded along with other unwanted items to create more space in the cramped cabin. The cabin was depressurized briefly, the PLSS packs and a jettison bag were thrown out, and the hatch was closed again. One PLSS fell near the ladder footpad and the other rolled out further, clearly visible in photographs taken out of the LM windows to document the EVAs. They are indicated in Figure 202.

The various sample containers and other items were weighed and the weights relayed to Earth to ensure the LM liftoff weight was known and items were roughly balanced. An LM communications antenna was checked, and then a short crew debriefing was carried out while surface activities were still fresh in the astronauts' minds. They were asked about the texture, colour and dustiness of large rocks on the rim of Cone crater, the coring activities, layering in the trench Shepard dug at Station G, the difficulty of climbing up to Cone crater, and the appearance of various craters and rocks. Shepard closed the discussion by saying "It's fantastic up here".

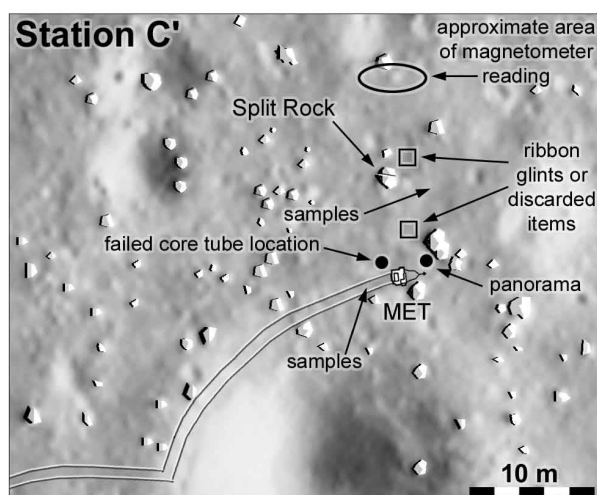
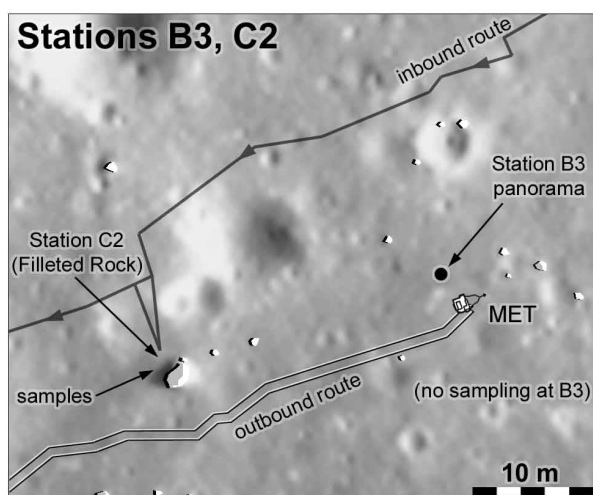
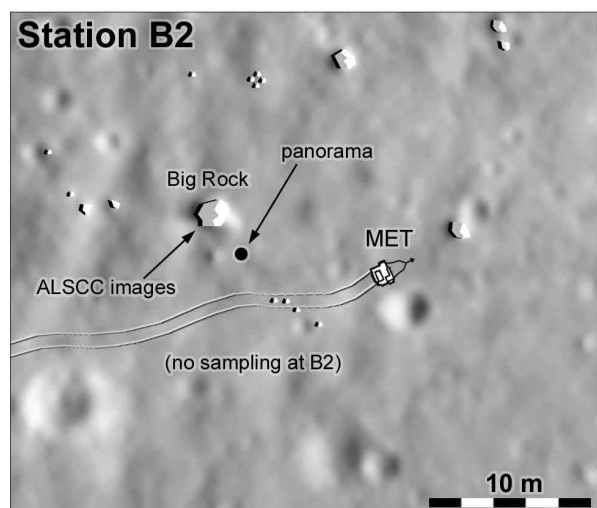
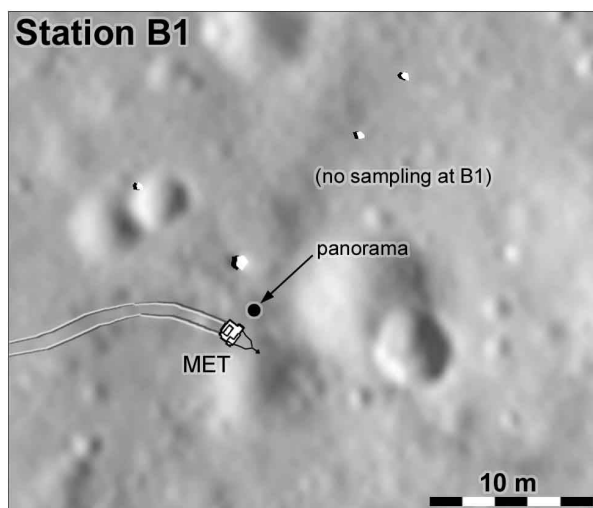
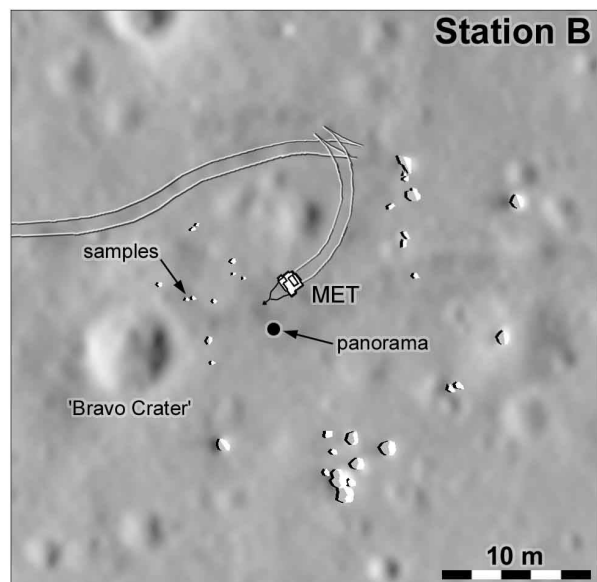
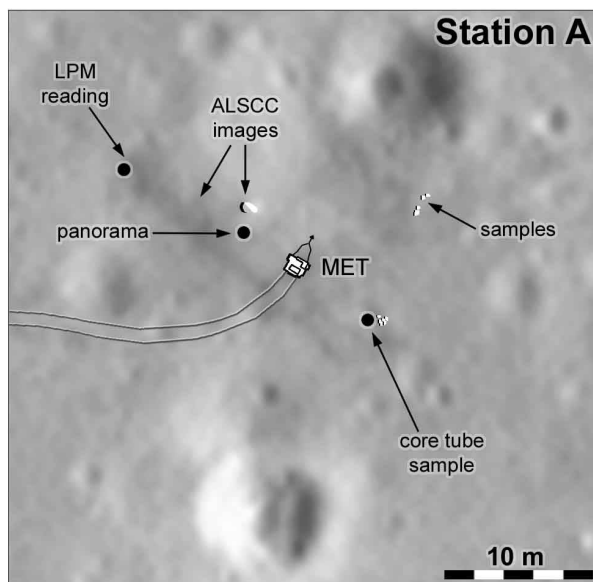


Figure 205: Apollo 14 traverse station plans. The images are composites of multiple LROC images except at Station C1, which is part of image M175388134R.

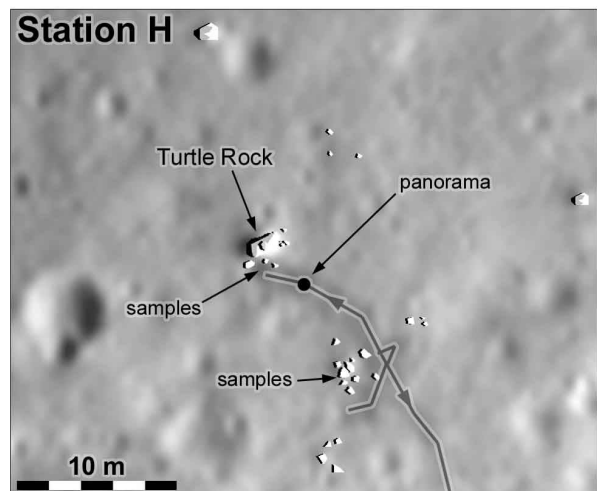
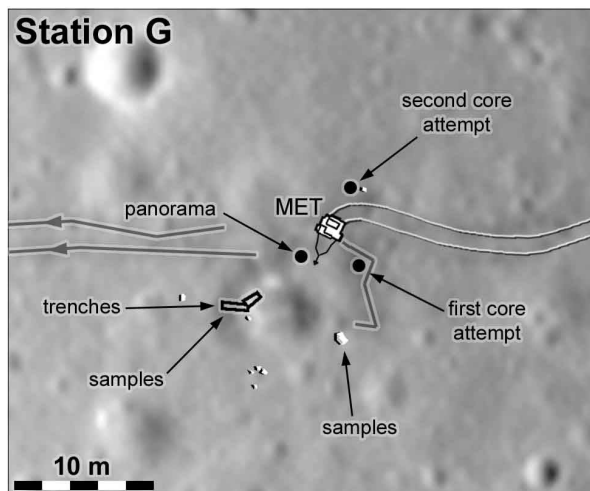
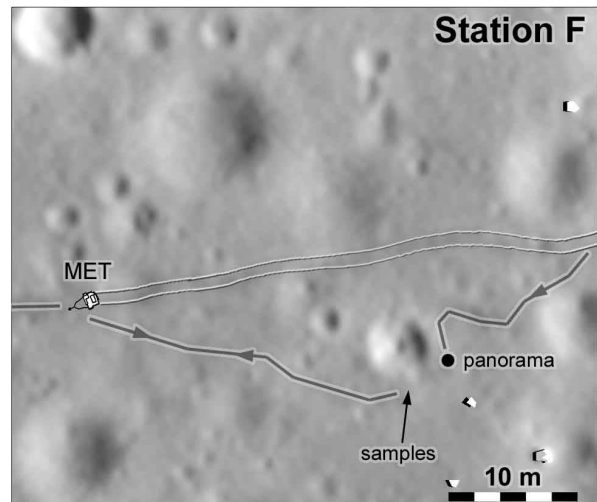
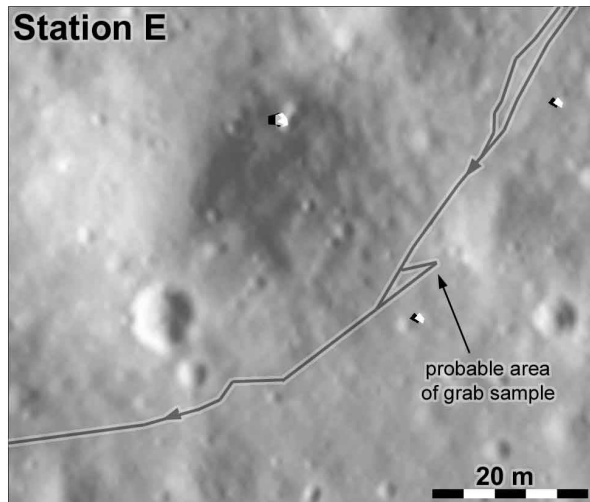
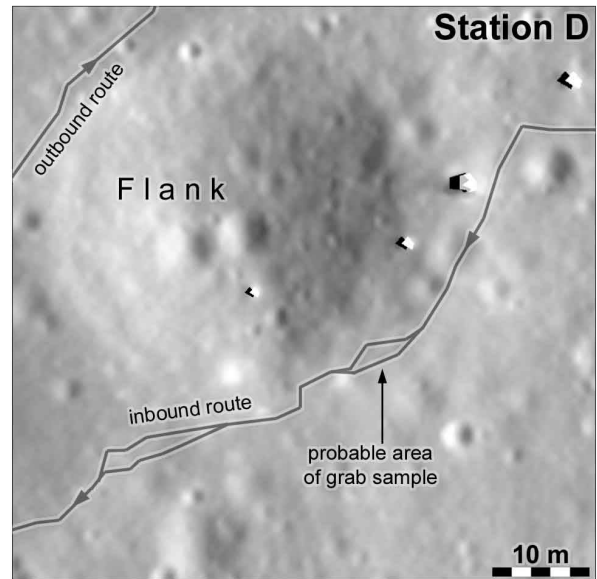
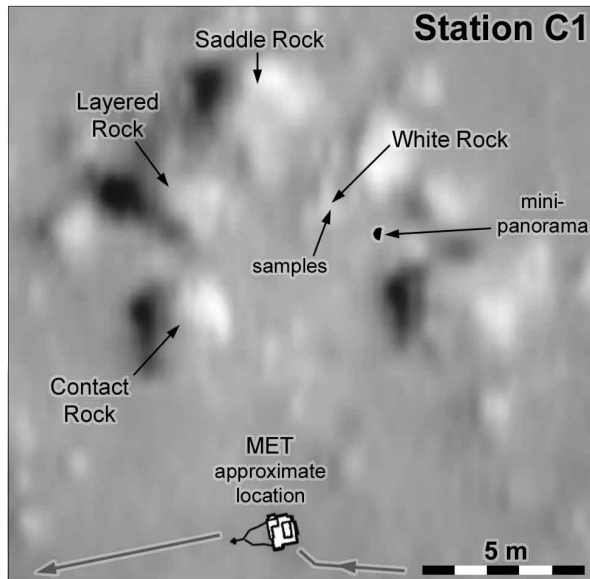


Figure 206. Apollo 14 traverse station plans. The images are composites of multiple LROC images.

Houston relayed news that Stu Roosa in the Command Module had seen the LM on the surface during two passes over the site, and light reflected from the ALSEP once. The LM High Gain Antenna was still a cause of concern, making unexpected noises as it moved. It had been unreliable before launch and should have been fixed. The crew had a meal and prepared for liftoff, receiving instructions from Houston on values to be entered into the flight computer and discussing arrangements for communication and docking to address potential problems. A test-firing of the ascent stage thrusters moved the flag and blew over the S-band antenna. The firing was also detected by the seismometer. The flag had also been moved by the cabin depressurization when the PLSS units were ejected.

The total time spent on the lunar surface was 33.5 hours. The LM took off at 18:49 UT on 6 February, and 40 seconds later Mitchell, looking out of the window, said “And here we're going across Cat's Paw”. No feature named Cat's Paw was shown on any Apollo 13 or 14 map, though the name had been used by Apollo 11 (Figures 141, 142, 145, 146). This may have suggested itself to Mitchell on the spur of the moment, or he might have recalled a very informal name used during training but never recorded. The feature it refers to is not obvious but a likely candidate would be the crater cluster consisting of Old Deep and the smaller craters on its west side (Figure 169D). Mitchell did not recall the use of the term when asked about it in 2010 (Ken MacTaggart, personal communication, 8 November 2010).

Detailed plans of the Apollo 14 EVA 2 traverse stations (Figure 205, 206) record activities at each station. Most of these are sites where panoramas were made and, in most cases, where samples were collected (S). The MET is shown where it appears in the panorama, with its tracks leading up to that point. All positions are approximate. Station B3 (right) also includes the sampling stop referred to as Station C2. Stations D and E were very short stops for ‘grab samples’, not documented with images. At Station G the first core sample was unsuccessful and the second partly successful, in retrieving regolith samples.

Most of these plans are drawn over enlarged composites of eight LROC NAC images with morning lighting, augmented (at stations A, B, B3, C', C1, G and H) with information from illustrations in Swann *et al.* (1977) and NASA (1971c), and from surface images. Station C1 is from a single image, M175388134R.

Apollo 14 returned images from under its ground track, and over a broad area at lower resolution during its departure from the Moon. Special imaging included extensive colour photography, very high resolution images of the Kant region for future site selection, and zero phase imaging. The latter images, taken looking in the same direction as the incoming sunlight, as if to view the spacecraft's shadow, reveal surface texture information to assist geological analysis. Figure 201 shows the extent of image coverage for Apollo 14.

Figure 202 shows the locations of two impact sites associated with Apollo 14, produced by the SIVB upper stage and the LM ascent stage. Figure 203 locates the SIVB site. The SIVB was expected to impact within 600 km of 1.60° S, 33.25° W. The impact occurred at 6:41 UT on 4 February and tracking suggested the location was 7.82° S, 26.00° W, 300 km southeast of the target. The Apollo 12 seismometer, 170 km away, recorded vibrations from the impact for two hours. By the time Apollo 16 images became available the location of the SIVB impact had been refined to 8.02° S, 26.02° W. Ewen Whitaker (1972) found the 40 m diameter crater at the centre of its dark ray system at 8.17° S, 25.95° W. Figure 203 shows the location of the crater in LROC images with updated coordinates 8.179° S, 26.031° W. The targets and tracking positions are from NASA (1971a), NASA (1971b) and MSC (1971b).

Figure 204 shows the location of an unusual impact feature which is probably the impact scar made by the Apollo 14 LM ascent stage (LMAS). The LMAS separated from the Command module after it was unloaded and was then slowed to fall to the surface so it would create a signal for the seismometer. The Apollo 14 Final Flight Plan, dated 18 January 1971, describes the targeting. The original version of the Flight Plan was compiled by 23 December 1970 but changes dated 11 January 1971 were made before it was released. The Apollo 14 LMAS was to be targeted at 3.50° S, 19.27° W (19.29° W in the original version). If the Apollo 14 ALSEP was not operating properly the impact would be targeted near the Apollo 12 site at 3.04° S, 24.64° W (3.32° S, 23.38° W in the original version) to take advantage of that seismometer.

Whitaker (1972) observed a dark spot near the expected position of the Apollo 14 LM ascent stage impact in Apollo 16 metric frames 2508-2515. These were high oblique images showing the limb with the impact site far from the

ground track and near the limb. The dark spot became darker as it approached the limb and was difficult to see in the early images of the sequence. When the dark appearance of some spacecraft ejecta was recognized Whitaker identified this as the probable site of the LM impact, but the crater itself, thought to be about 18 m across if circular, was not resolved. The LM target was 3.50° S, 19.27° W but tracking suggested an impact at 3.42° S, 19.67° W and Whitaker's dark spot was at 3.37° S, 19.4° W. LRO images show a circular crater 100 m in diameter at that location with bright and dark ejecta. It resembles a fresh natural impact rather than the elongated depression with faint downrange ejecta seen at the Apollo 12 LM site (Figure 167) and ejecta patterns seen at the impact sites for GRAIL, LADEE, Chang'e 1 and other de-orbited spacecraft.

A dark spot is visible at 3.420° S, 19.637° W (Figure 213D) which includes several rays of dark material emanating from a gouge roughly 25 m long and 4 m wide. It is very similar to the features seen at the Apollo 12 LM impact site except that no downrange spray of shrapnel-like secondary impacts is visible at this location. This feature is probably the LMAS impact site. It is 10 km from the target, 6 km from Whitaker's marking and 800 m east of the tracking position.

MSC, 1971b. *Apollo 14 mission report*. MSC, Houston, Texas, May 1971.

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Whitaker, E. A., 1972. Artificial lunar impact craters: four new identifications. *Apollo 16 Preliminary Science Report*, NASA SP-315, pp. 29-39 to 29-45. Washington, D. C.: NASA.



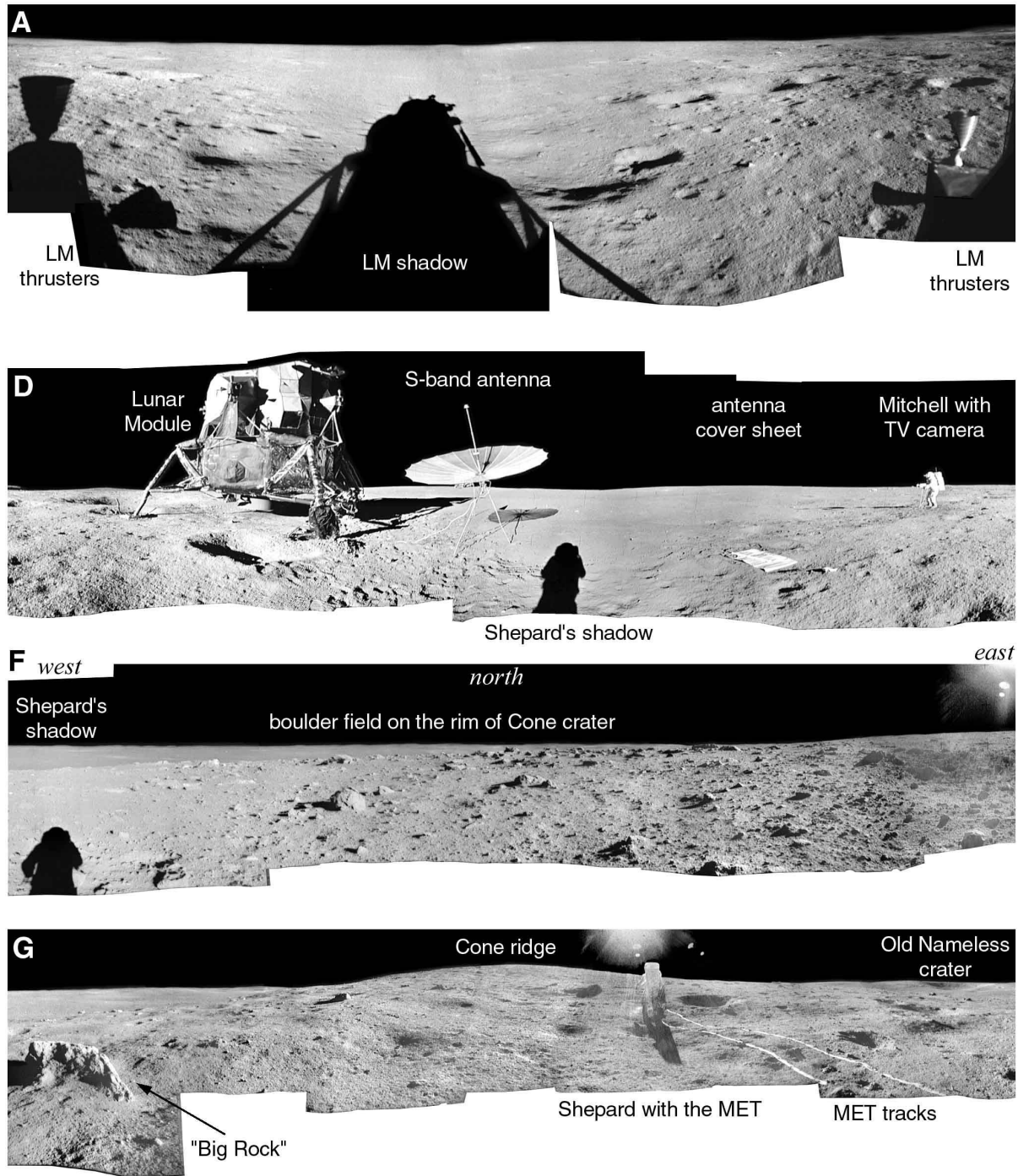
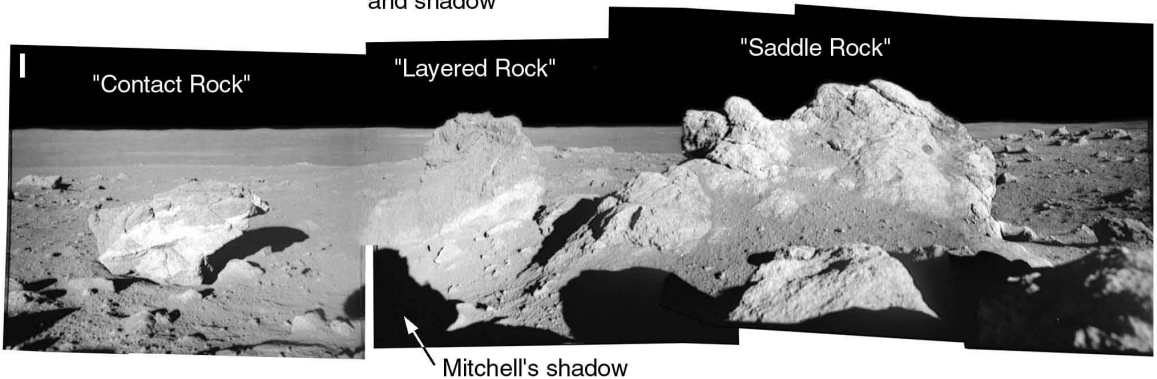
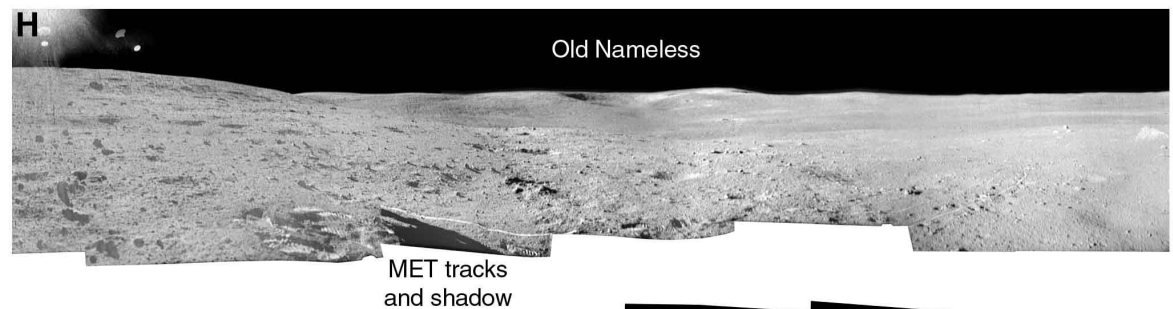
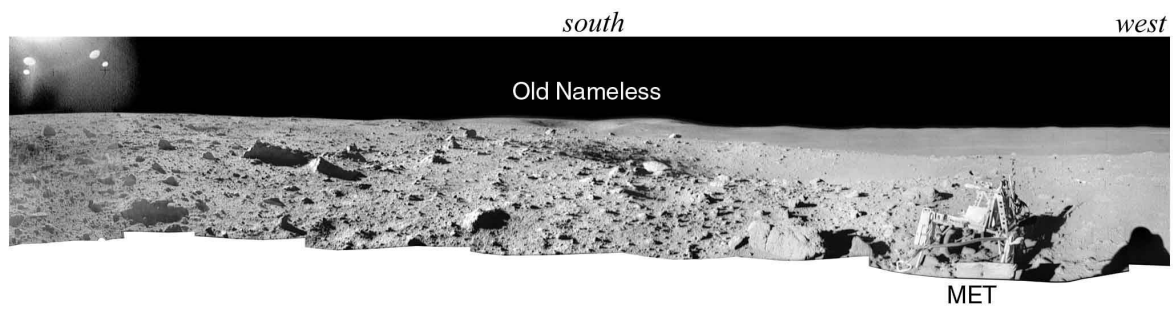
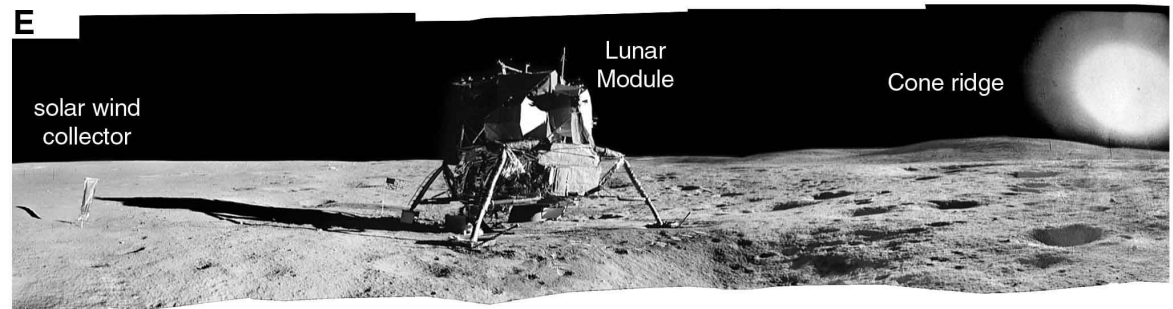
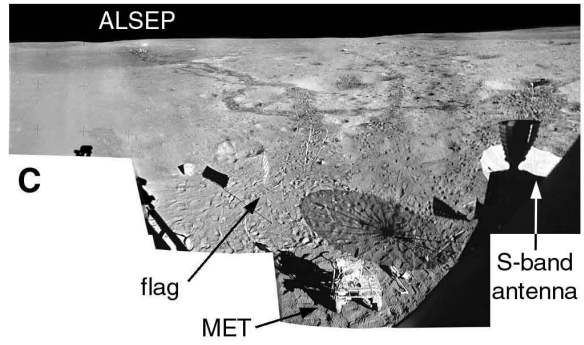
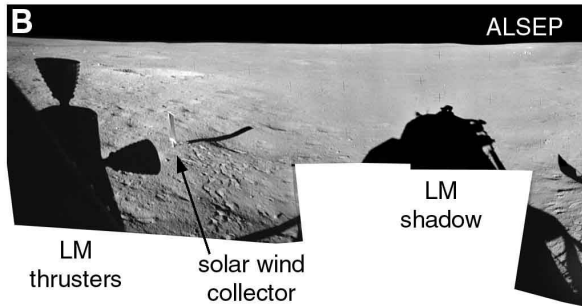


Figure 207 (both pages): Apollo 14 panoramas. **A**: composite view from both windows after landing. **B**: view from the left window after EVA 1 showing the solar wind collector and ALSEP (small bright dots at right). **C**: view from right window after EVA 2 showing items left on the surface. **D**: LM from the east. The antenna cover shaded the MET between EVAs to prevent overheating. **E**: LM from the south, with Cone Ridge to the northeast. **F** (across both pages): Station C near the rim of Cone crater, showing rocky ejecta. The image of the MET is truncated to allow maximum visibility of the lunar surface. **G**: Station B2 seen during the ascent of the ridge. **H**: view of Old Nameless from Station B3. The MET and an astronaut cast shadows in the foreground, but only the shadows are visible in this compilation. **I**: boulders at Station C1, near the rim of Cone crater.



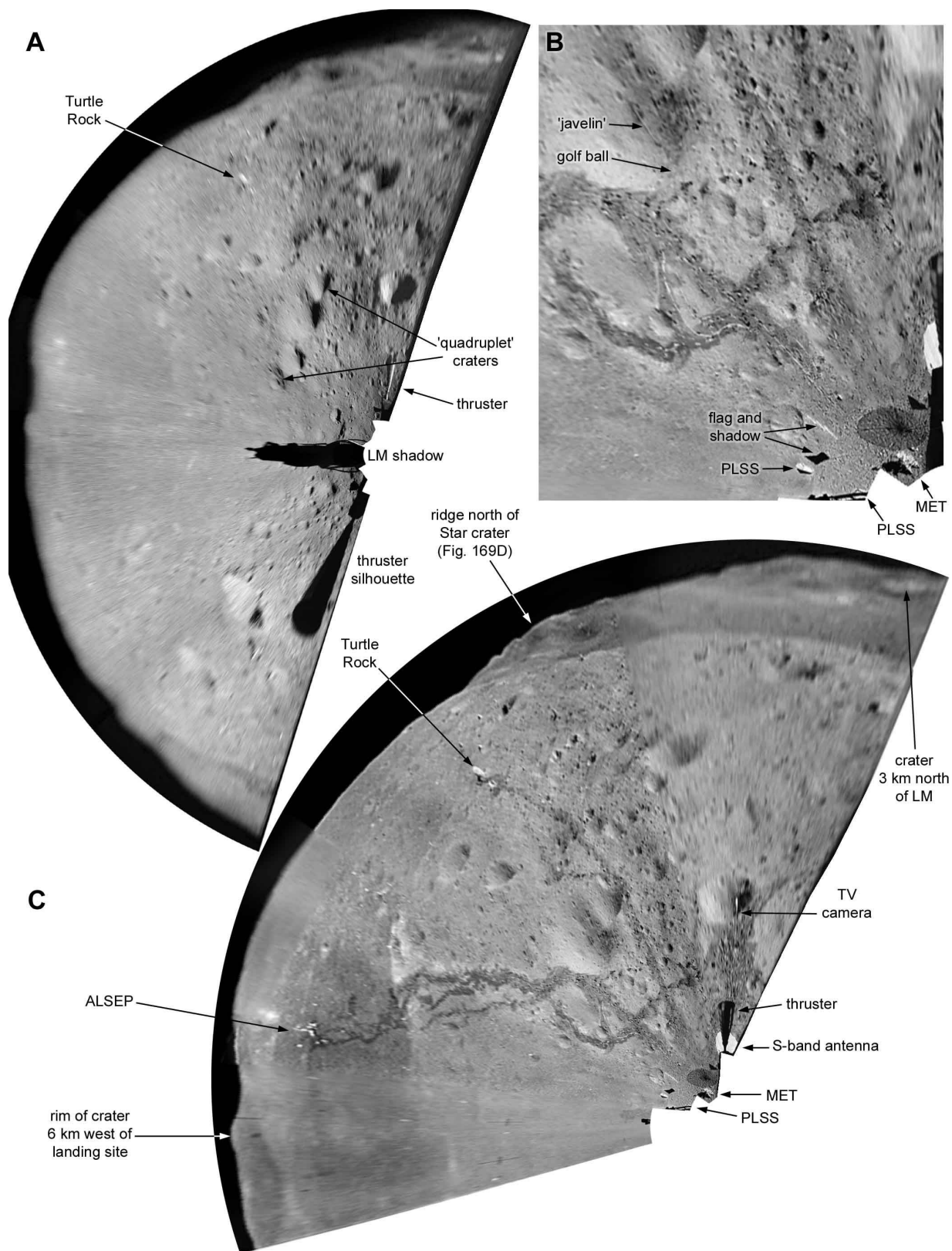


Figure 208. Reprojected Apollo 14 panoramas. A: view from LM windows after landing. B: post-EVA 2 view near LM (detail of C). C: post-EVA 2 window panorama showing tracks and the ALSEP.

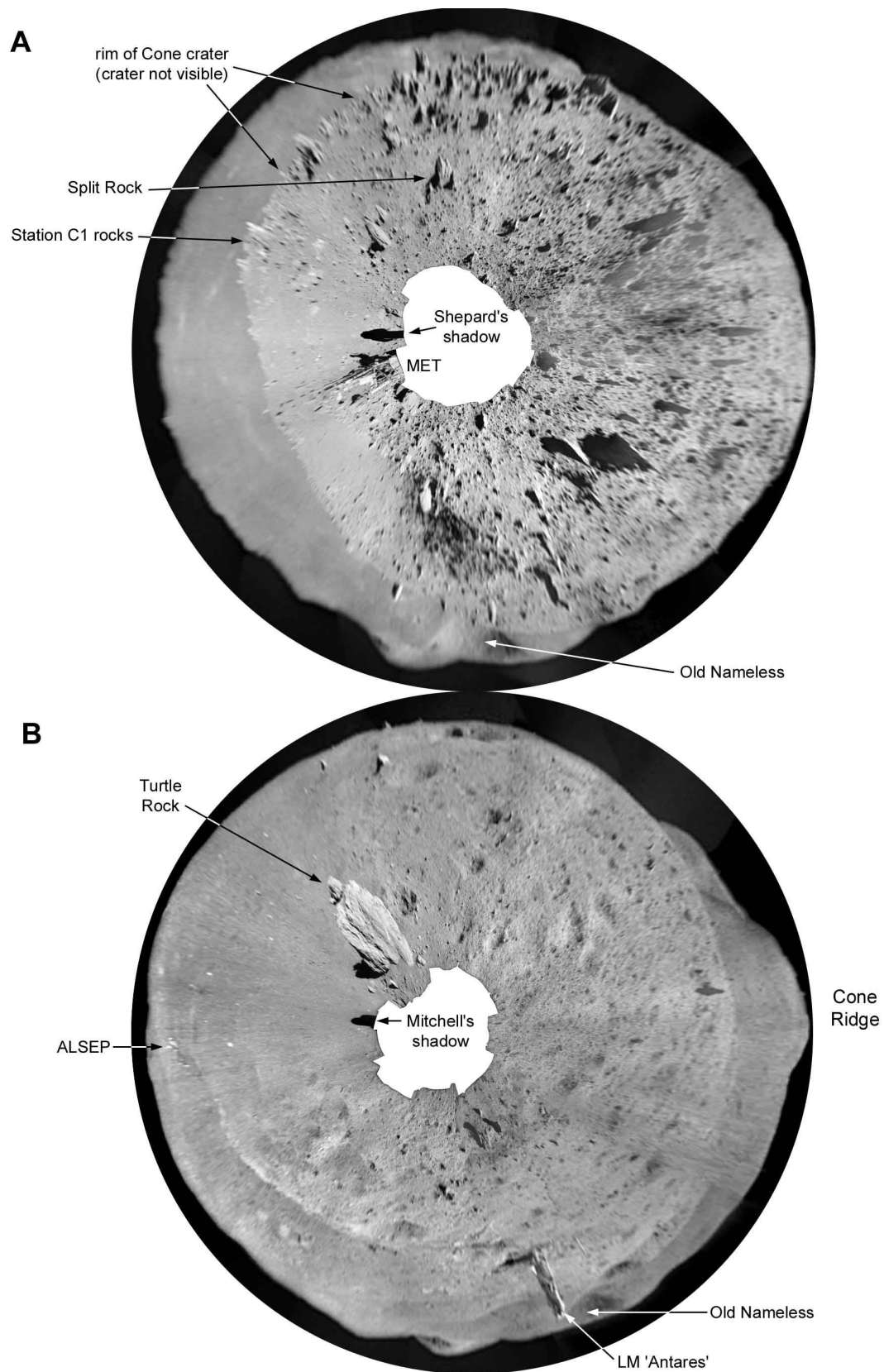


Figure 209. Reprojected Apollo 14 panoramas. A: Station C' near Cone crater. B: Station H near the LM.

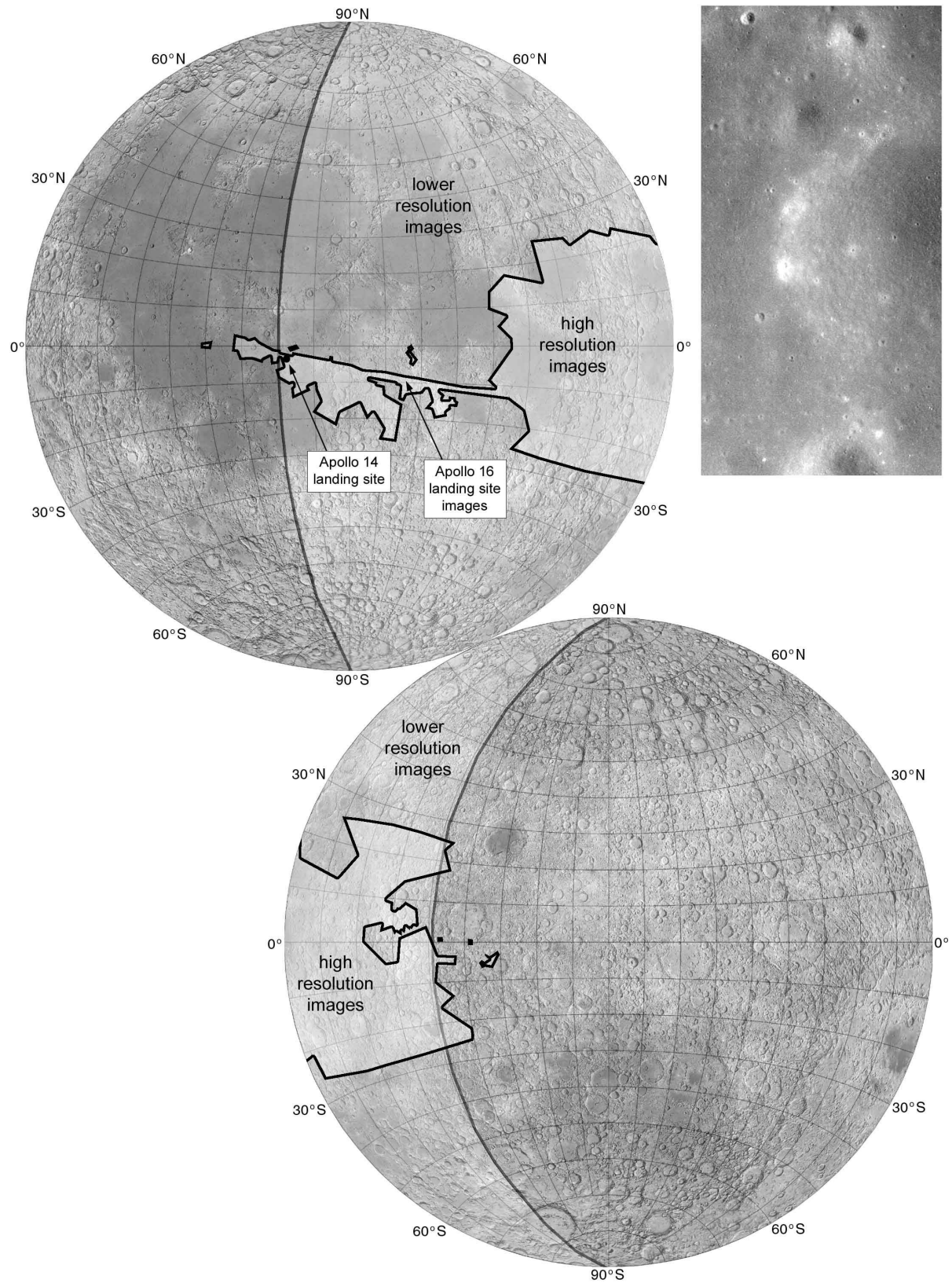


Figure 210: Apollo 14 orbital image coverage. The inset image is part of Hycon image AS14-80-10468 showing the floor of Theophilus, from a search for alternative Apollo 16 landing sites.

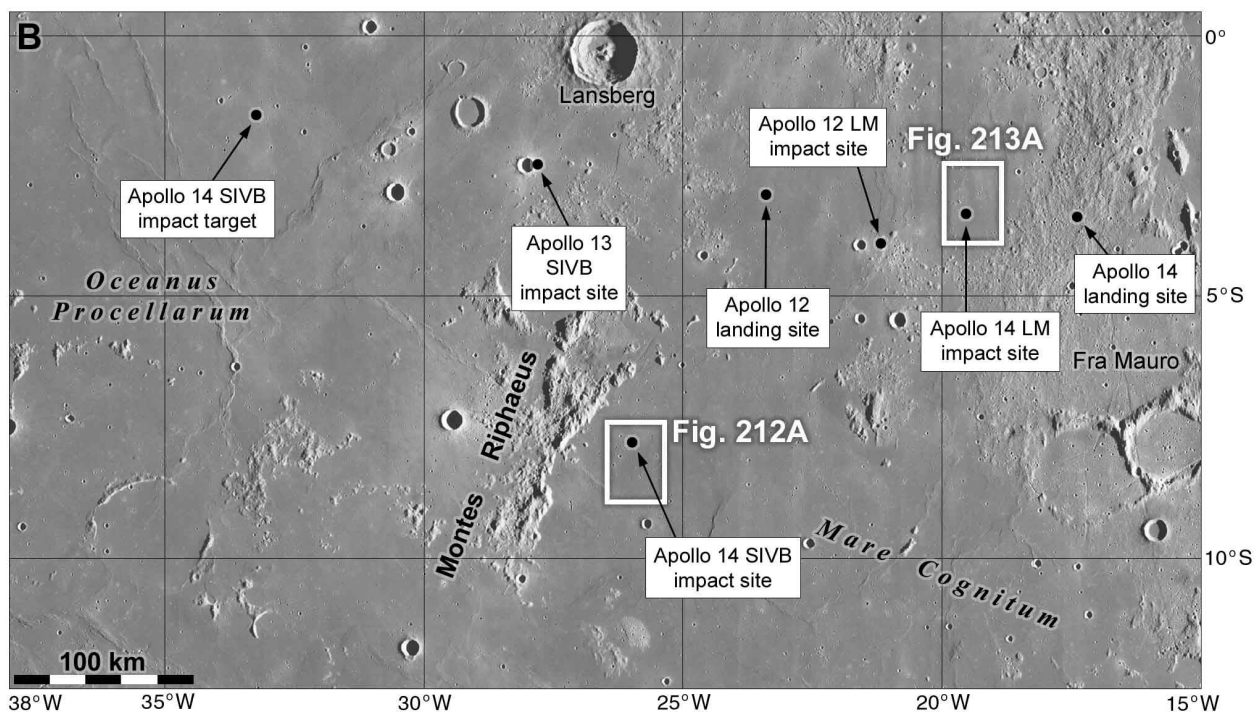
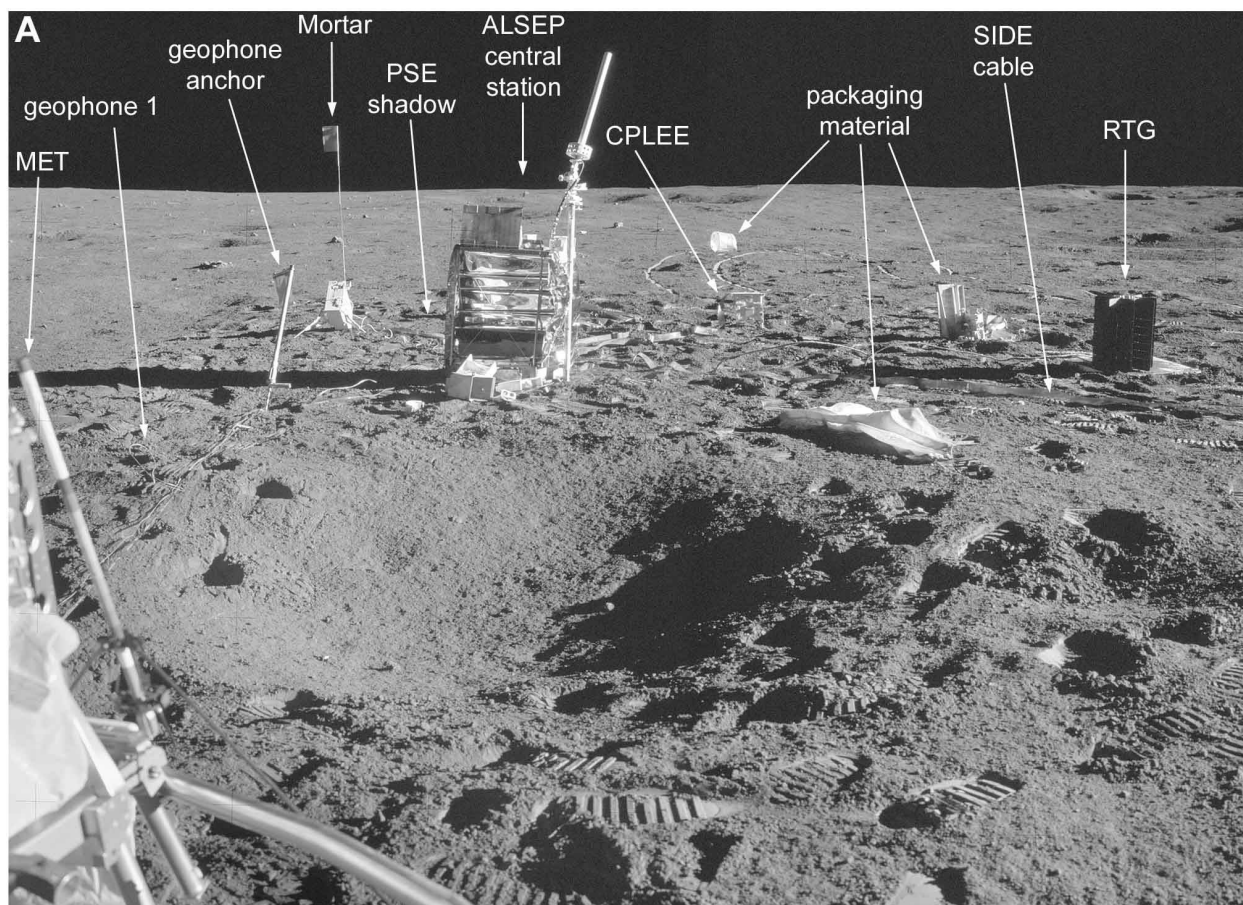


Figure 211. Apollo 14 ALSEP and impact sites. A: ALSEP mini-panorama, composite of images AS14-67-9375 and AS14-67-9376. B: locations of the SIVB and LM ascent stage impact sites

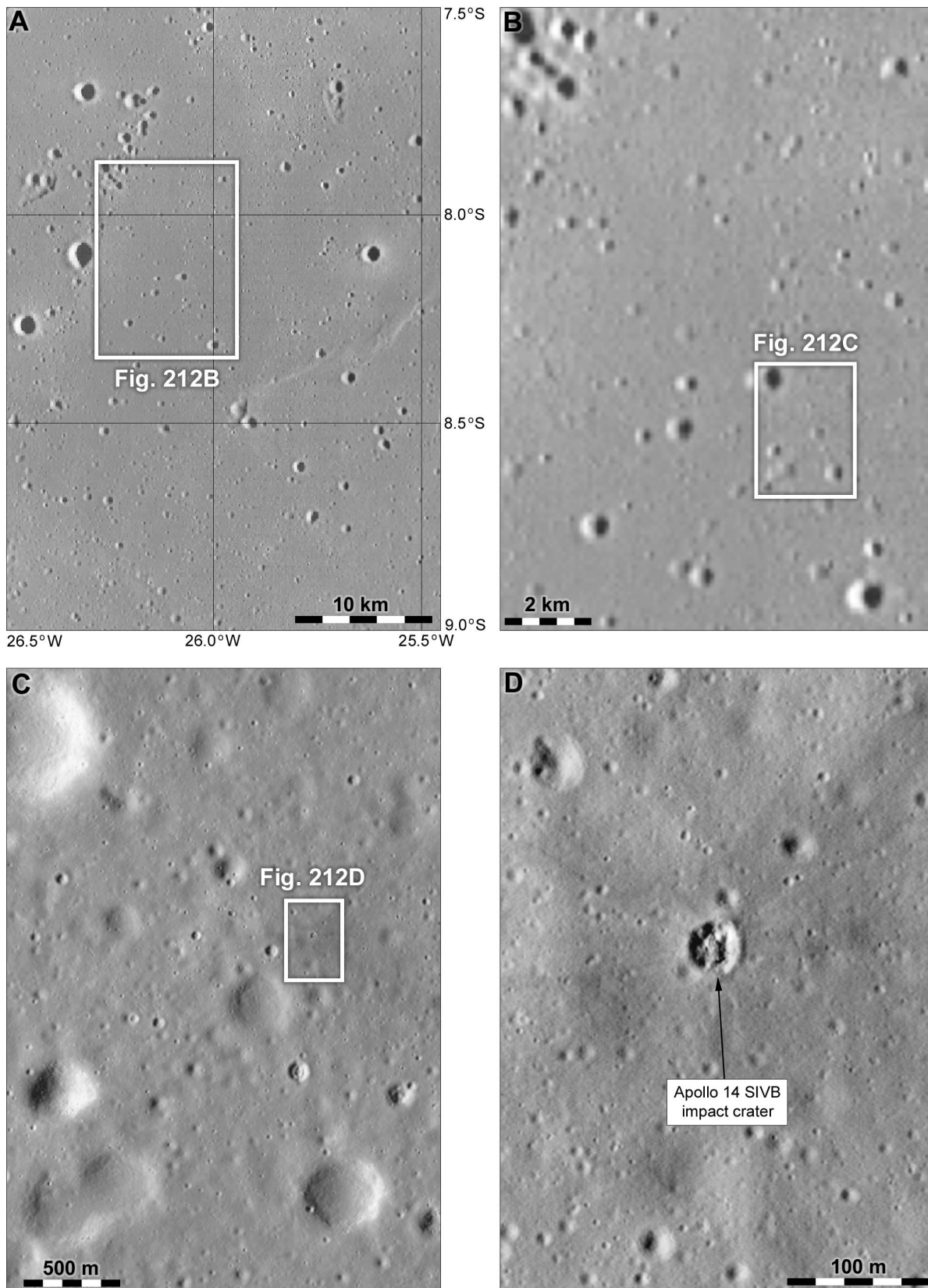


Figure 212: Apollo 14 SIVB impact site. C and D: LROC image M1111982941L.

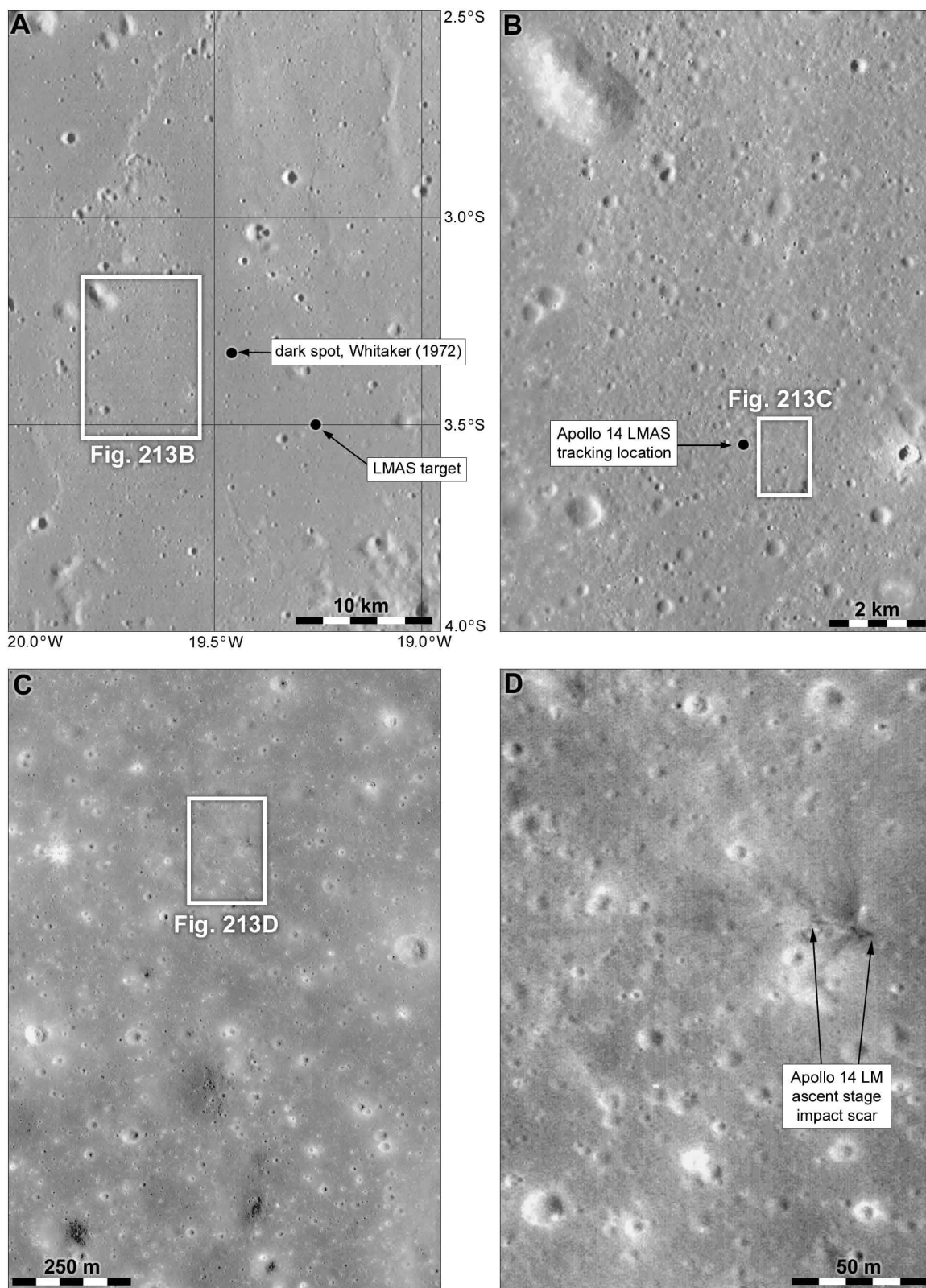


Figure 213. Apollo 14 LM ascent stage impact site. D is a composite of LROC NAC images M111721735L and M1136683930L.

03 February 1971: Science Working Panel

The Panel met on 03 February and 30 March to consider Apollo 15 EVA plans. A rover, the Lunar Roving Vehicle (LRV) would be carried for the first time, but suitable walking EVA plans were required if the rover failed or could not be ready in time for launch. Only the Hadley North site (site 1 in Figure 178C) was now being considered because it allowed a safe descent after flying over the Apennines while still landing close enough to the foot of a mountain to visit it. The sampling goals included the plains material at the landing site, Imbrium basin rim (Apennine Front) material from the base of Hadley Delta, the mountain south of the landing site, and the rim of Rima Hadley, the sinuous valley to the west. Several plans presented at the Panel meetings are shown in Figure 214, differing in many details from the proposed EVAs shown in Figure 178D.

Figures 214A and 214B show LRV and walking traverse plans from the February SWP meeting. The maximum walk-back distance was assumed to be roughly 3 km, limiting the range of exploration but still fulfilling the chief science goals of the mission. Figure 214C shows modified EVA routes and activities from the March meeting. A cluster of craters and hills north of the target point was now interpreted as a possible volcanic complex, and had become an additional sampling goal, though it would not be accessible to walking astronauts. The background is a mosaic of LRO NAC images.



03 June 1971: Apollo Site Selection Board

The Board met to finalize Apollo 16 site selection and to begin considering the site for the last landing. At the previous meeting Descartes was recommended as the Apollo 16 site with Copernicus central peaks as an alternative, and Marius Hills as Apollo 17's target with Copernicus or a new highland site as alternatives. Now, however, the scientific priority for both remaining Apollo missions was to sample highland sites. Since Copernicus ejecta was apparently sampled by Apollo 12, that crater was less of a priority. Descartes and Alphonsus were now favoured for Apollo 16.

Another alternative was the Kant Plateau, a highland area east of Descartes. Apollo 14 provided high resolution stereoscopic images from its Hycon camera, which failed before reaching Descartes but provided good images between Theophilus and Kant. Carroll Ann Hodges (USGS) selected three sites along the photo strip (Figure 206A-D). In order of 'geological promise' these were: (Site 1) frame AS14-80-10468, 11.0° S, 26.3° E, a flat area just north of the central peak of Theophilus, with a fresh 200 m diameter crater and an LRV route to the central peaks; (Site 2) frame AS14-80-10629, 9.5° S, 18.3° E, west of Kant, landing in a flat area at the centre of the frame, with hilly Cayley Formation material and a fresh 100 m diameter crater; (Site 3) frame AS14-80-10511, 10.6° S, 24.2° E, Theophilus ejecta, with three craters in an arc, one fresh with a blocky rim. These sites were rejected because only a very narrow strip of high resolution coverage was available. Alphonsus was rejected because its geology was poorly understood and very old material, a high priority, might be difficult to find under Imbrium ejecta. It might still be suitable for Apollo 17 if good photography from Apollo 16 helped resolve these issues. Thus Descartes was adopted for Apollo 16, though there was still uncertainty about the exact landing site.

The schedule change for Apollo 17, now set for the end of 1972, would again make Tycho accessible so it was once more in contention. The Apollo 17 priority sequence was now: (1) Tycho or Davy; (2) the highland region southwest of Mare Crisium, if Apollo 15 orbital data showed a compositional difference between that area and the mountains at the Apollo 15 site; (3) Gassendi central peaks; (4) (low priority) Copernicus. The 'southwest of Crisium' region was as far as Apollo could hope to get from Imbrium ejecta, offering a good chance of finding older material. This section is based on ASSB minutes and the Science Working Panel minutes from 11-12 May 1971.



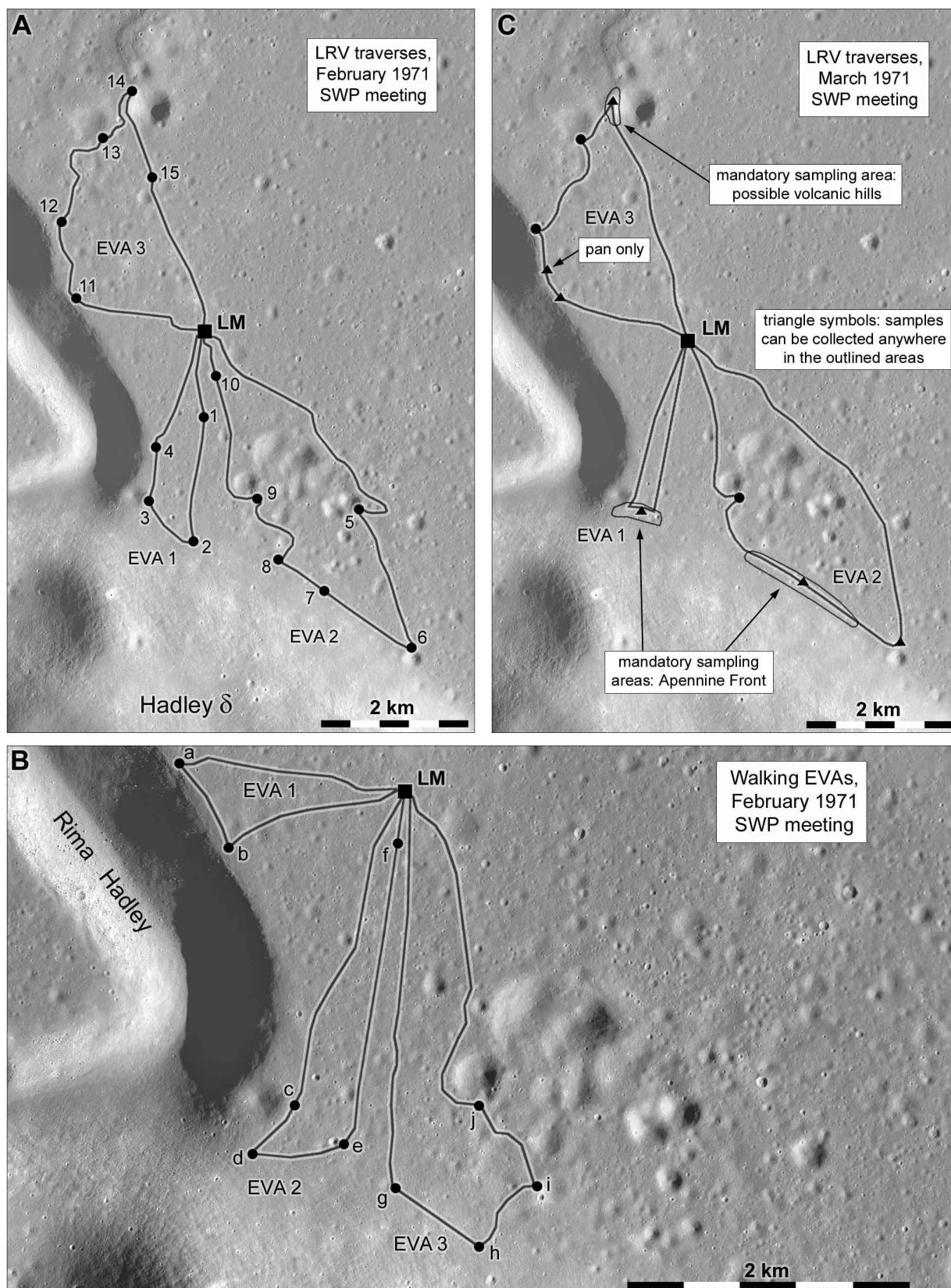


Figure 214: Apollo 15 EVA plans from the Science Working Panel, February and March 1971.

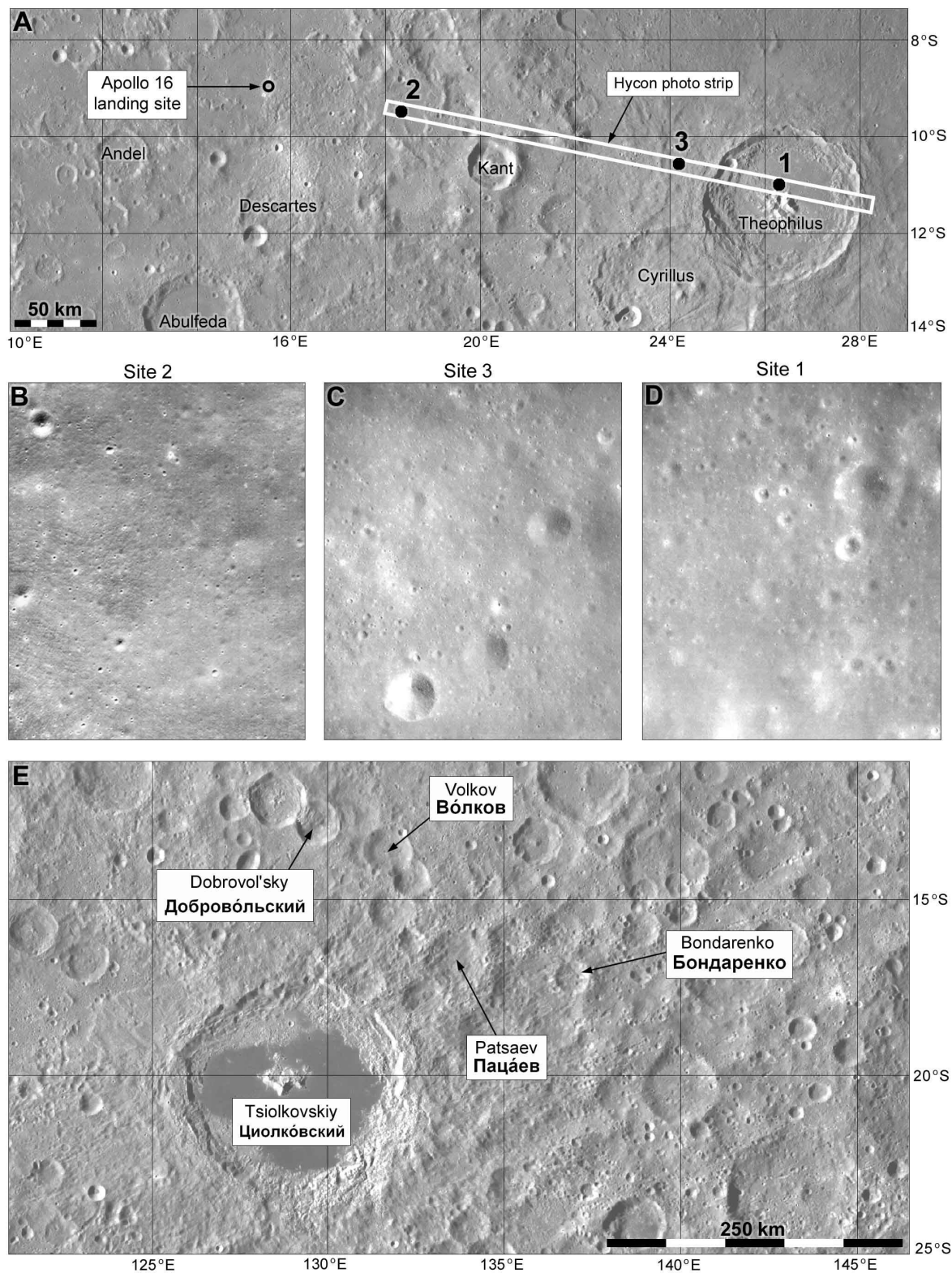


Figure 215. Future sites and Soyuz 11 craters. A: location of the Apollo 14 Hycon image strip with potential Apollo 16 sites. B, C, D: Hycon images AS14-80-10468, AS14-80-10629 and AS14-80-10511 respectively, showing alternative sites for Apollo 16. Each image spans 4 km top to bottom. E: craters near Tsiolkovskiy commemorating the Soyuz 11 cosmonauts and Valentin Bondarenko.

Figure 215 shows the Apollo 16 landing site north of Descartes and the three Kant Plateau sites (black circles) briefly considered for that mission. The Hycon image strip is shown as a white rectangle. Below it are Apollo 14 Hycon images of the three sites, arranged from west to east.



06 June 1971: Soyuz 11

Soyuz 11 launched from Baikonur at 4:55 UT with its backup crew, Georgi T. Dobrovolskiy, Viktor I. Patsaev and Vladislav N. Volkov. The prime crew (Alexei A. Leonov, Pyotr I. Kolodin and Valeri N. Kubasov) were replaced when Kubasov became ill before the launch. They docked with Salyut 1, the first time a space station was occupied in orbit. After several technical problems including a small fire and a jammed telescope cover, they cut short their flight and deorbited on 29 June. The 23.8 day flight was the longest yet made by any crew. A valve failure caused a fatal loss of air pressure in the capsule during re-entry. The crew are buried in the Kremlin wall in Moscow and are commemorated by craters near Tsiolkovskiy (Figure 215E). A nearby crater commemorates Valentin V. Bondarenko, a cosmonaut in training who died in a fire during ground tests on 23 March 1961, in circumstances similar to those of the Apollo 1 astronauts. The details were only made public in 1986.



27 June 1971: Third N-1 Launch

This launch was not aimed at the Moon, and carried only a dummy lunar orbital module (LOK) spacecraft. The rocket began to lose control after 30 seconds and failed completely after 50 seconds, crashing 20 km from the Baikonur launch pad.



Later Apollo planning

Several studies related to the later Apollo missions and post-Apollo exploration are summarized here.

An Apollo landing at a highland site was a high priority, and Fra Mauro was not typical of the cratered highlands occupying most of the southern half of the nearside. Apollo planners had downgraded some highland sites such as Tycho and Censorinus, and other sites such as Davy and Descartes required additional 'bootstrap' images. This made a less interesting highland site already covered by good images seem worthy of a second look. Head (1970) summarized the geology of the Lade site in Lunar Orbiter 3 site III-S-10 (Figure 119), which included Imbrium ejecta and a possibly volcanic plains-forming material called the Cayley Formation, of the type also mapped at Descartes. A landing near a very young crater roughly the same size as Cone crater at Fra Mauro (Figure 119, III-S-10, site 1) would sample sub-surface material and also provide samples of 'patterned ground' (a regolith texture produced by downslope movement). A landing on Cayley material (site 2) would permit sampling of the plains and nearby ridges. These locations are 1° 18' S, 13° 31' E (site 1) and 1° 43' S, 13° 24' E (site 2). Site 3 in that figure was now deemed unacceptable because of a ridge on the approach path. In the end, bootstrap imaging from Apollo 14 was able to certify Descartes for Apollo 16, and the Lade site was no longer needed.

The future of lunar exploration was in doubt as the Apollo missions progressed. Would the high levels of spending required for Apollo continue or would funding diminish? James Blahnik (1971) described an automated exploration program to follow Apollo if human exploration was curtailed. Rovers, instrument deployments and sample returns would continue lunar exploration at lower cost. The Illinois Institute of Technology Research Institute (IITRI) and

USGS studied possible sites and activities for this program. They identified 23 distinct types of site, and as some might need to be visited at more than one location, about 32 actual sites should be investigated. Some of these were close to each other, so a total of between 25 and 30 landing sites might satisfy the needs of the program. The list was passed to USGS Flagstaff geologists who had their own list of 17 types of site (Table 62).

Table 62. Reference science sites from Figure 4-1 in Blahnik (1971)		
Site	Name	Geology
1	Alphonsus	Dark halo crater
2	Marius Hills	Volcanic materials
3	Timocharis D	Red-blue mare boundary
4	Ptolemaeus	Plains on crater floor
5	Flamsteed	Extrusive volcanics, ring-dyke?
6	Tycho	Large young crater
7	Oriente	Concentric scarp, faults
8	Copernicus	Central peaks, walls
9	Stadius	Ghost ring (buried crater)
10	Davy crater chain	Crater chain regarded as volcanic
11	Aristarchus	Lava flows
12	Ariadaeus rille	Graben structure
13	Janssen	Circum-basin material
14	Proclus	Dome material
15	Alpine valley	Alpes Formation
16	Schrodinger	Farside basin, peak ring
17	Tsiolkovski	Farside mare-filled crater

Blahnik's report attempted to reconcile these lists (Table 63), which included in priority order all the major geologic units mapped at USGS and individual features of interest such as lava tubes, volcanic domes and crater central peaks. It presented a scenario of a possible exploration program to follow Apollo, beginning with three orbiters to perform geophysical and compositional surveys of the whole Moon in 1974, 1975 and 1976. In each of those years a single robotic landing would explore structures and deposits associated with major impact basins and, in 1976, the highlands themselves. Two landings in 1977 would continue the investigation of the highlands. A landing in 1978 would explore the structures and ejecta around one of the large impact basins, Oriente, Nectaris or Crisium, and one each in 1978 and 1979 would look for the oldest lunar materials. A final landing in 1979 would be devoted to a special topic such as a polar site, water or other volatiles in a dark-halo crater deposit, or a previously unsampled geological unit.

From these considerations a second list of 17 sites was compiled (Table 64). Figure 216 shows the sites listed in Tables 62 and 64 and the locations of the rover traverses are illustrated in Figures 217 and 218.

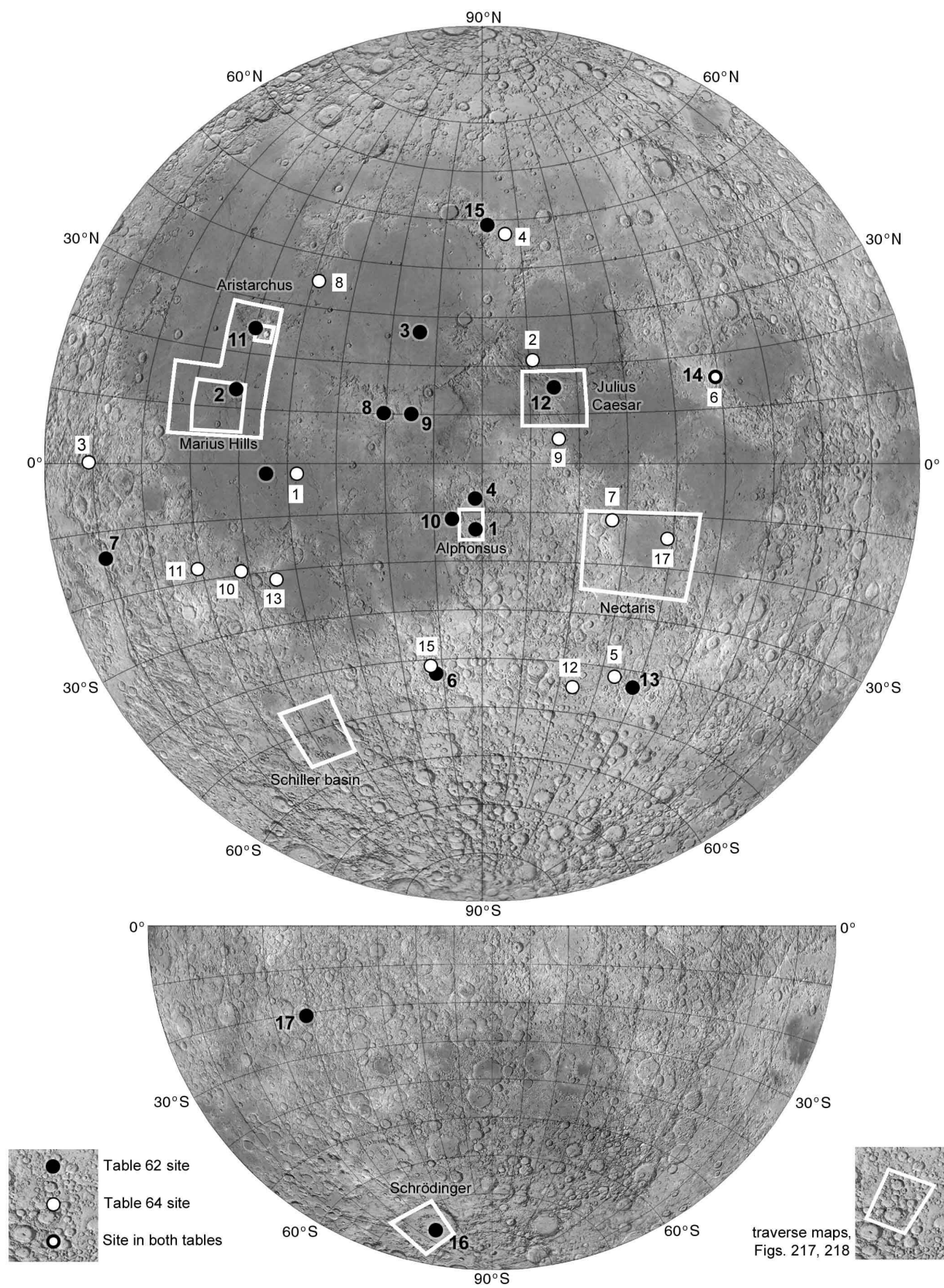


Figure 216. Exploration sites from Blahnik (1971).

An advanced rover might have a range of 500 km, allowing a traverse of 300 km and additional distance for detailed investigations along the path. Landing sites were selected to place several types of geological feature from the previous lists within reach of the rover. Two routes were illustrated in the main report, one in Alphonsus which could visit the central peak, the Ranger 9 impact site, and in an extended mission the floor of Ptolemaeus and other craters further north. The other, designed by David Scott (a USGS geologist, not the Apollo 15 astronaut) began at what was then considered a likely landing site for Apollo 17 in the Marius Hills. One option was directed north across Oceanus Procellarum to the Aristarchus Plateau, the other ran south through the Marius Hills, examining many domes, rilles and flows, and then explored the unusual swirl pattern at Reiner Gamma and the landing area of Luna 9 (Figure 217). Scott also advocated a landing in or near King crater on the farside at 5.5° N, 120.5° E. An unusual ridge extends from the south wall of the crater to its central peak, and its shape and several unusual dark markings suggested to Scott that it might be volcanic in origin. A specific landing point was not indicated.

Blahnik's report included an appendix providing more details of some of these activities. William Hartmann presented maps of 7 rover traverses to show what might be achieved by the suggested program of exploration (Figure 218). These included traverses at Aristarchus and Marius Hills which differed from Scott's, and a traverse in the Schrödinger basin on the farside which would again feature in exploration plans more than 40 years later.

Table 63. Ranked type area list from Blahnik (1971)

Site	Type area	Activities
1	Terra (highland) if not well sampled by Apollo	Sample return, geophysics, chemistry
2	Dark-halo crater	Sample return, deploy instruments (?), imaging
3	Volcanic dome field, rough domes	Sample return, imaging, geophysics, chemistry
4	Wrinkle ridge	Sample return (?), imaging, geophysics, chemistry
5	Contact between 'red' and 'blue' lava flows	Sample return, geophysics, chemistry
6	Highland plains unit	Sample return, geophysics, chemistry
7	Highland hilly volcanic material (Descartes)	Sample return, geophysics, chemistry
8	Possible extrusive ring (e.g. Flamsteed)	Sample return, imaging, geophysics, chemistry
9	Peak ring (basin concentric inner ring)	Sample return, imaging, geophysics, chemistry
10	Large recent impact crater	Sample return, imaging, geophysics, chemistry
11	Ranger or Apollo SIVB impact site	Imaging
12	Assimilated contacts at edge of mare	Sample return (?), geophysics, chemistry
13	Central peak 'active' volcano (e.g. Alphonsus?)	Sample return, imaging, geophysics, chemistry
14	'Active' volcanic site (LTP)	Samples, instruments, imaging, geophysics, chemistry
15	Crater chain	Deploy instruments, imaging, geophysics, chemistry
16	Concentric scarp around large basin	Deploy instruments, imaging, geophysics, chemistry
17	Ghost crater ring (e.g. Stadius)	geophysics, chemistry
18	Exposed fault scarp in crater or mare	Deploy instruments, imaging, geophysics, chemistry
19	Collapse lava tube	Imaging, geophysics, chemistry
20	Sinuuous rille (e.g. Rima Hadley)	Sample return (?), imaging, geophysics, chemistry
21	'Mantled ring' (impact into liquid lava?)	Geophysics, chemistry
22	Lava flow	Sample return (?), imaging, chemistry
23	Linear rille	Imaging, geophysics, chemistry
24	Radial lineaments around basin	Imaging (?), geophysics, chemistry
25	Grid system lineaments	Imaging (?), geophysics, chemistry
26	Far side site	Sample return, geophysics, chemistry
27	Polar site	Sample return, geophysics, chemistry

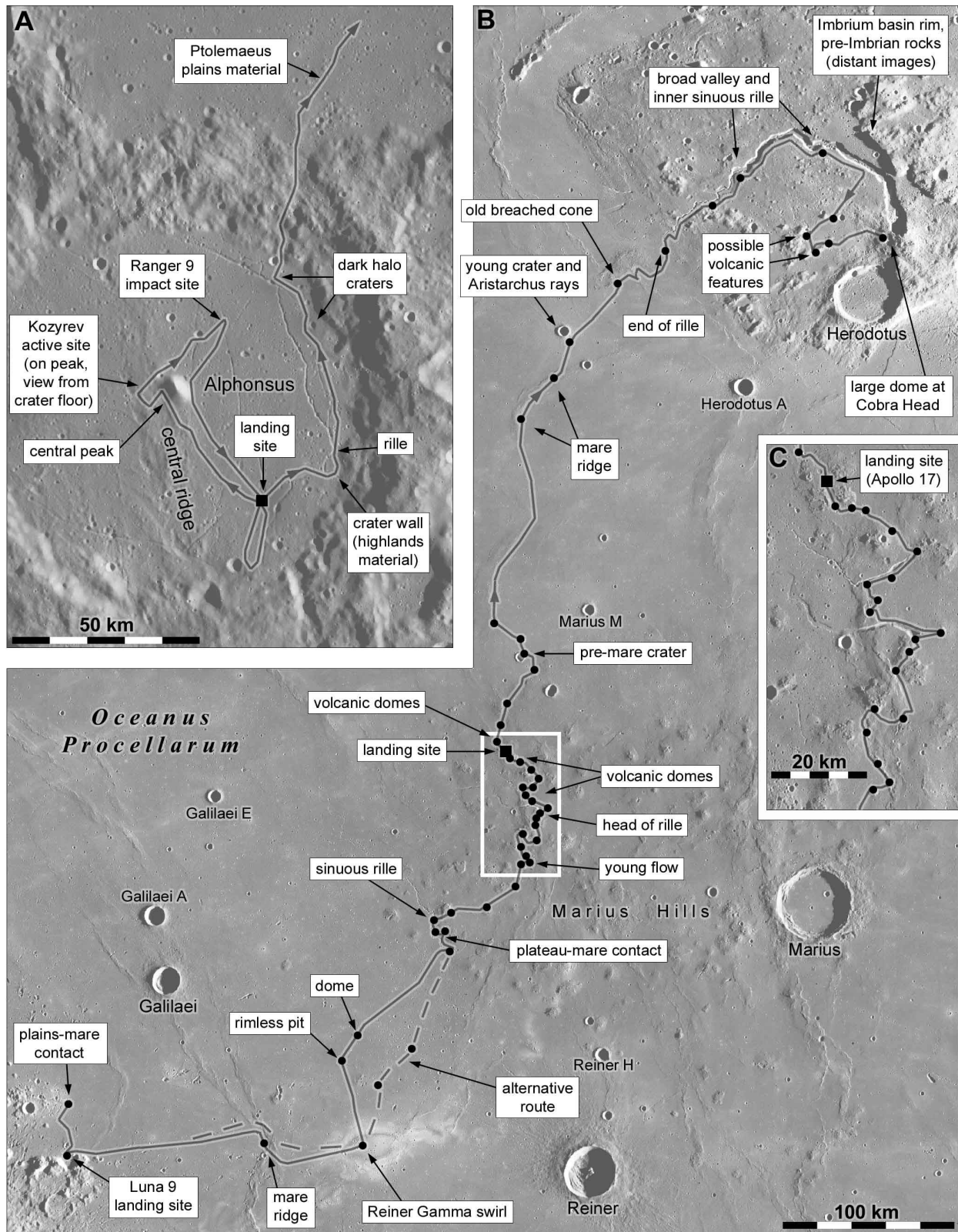


Figure 217. Traverses by robotic rovers (Blahnik, 1971). A: Alphonsus crater traverse. B: Oceanus Procellarum traverses north and south from a Marius Hills landing site. C: detail of the traverse in the Marius Hills.

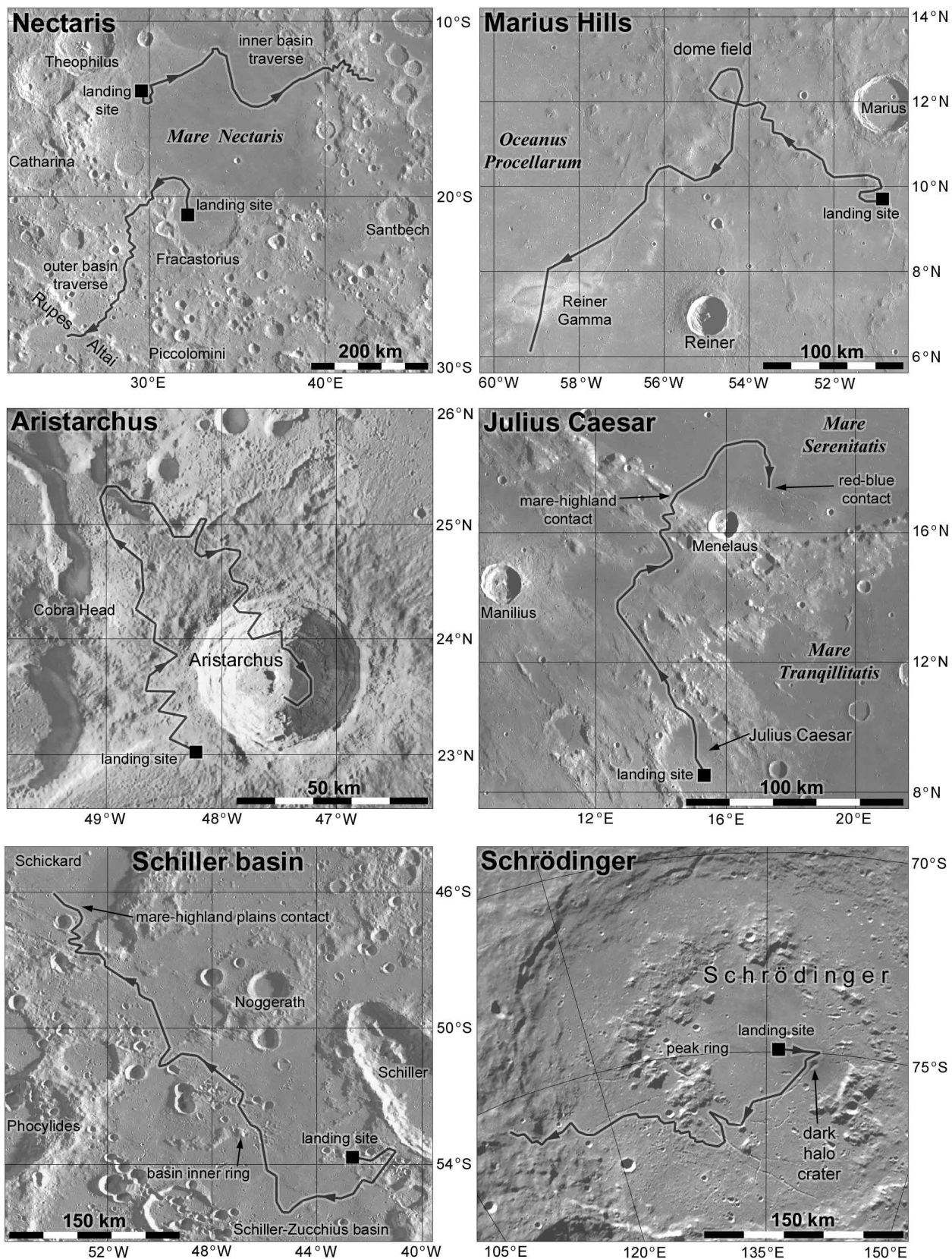


Figure 218. Robotic traverses designed by William Hartmann (Blahnik, 1971).

Table 64. Reference science sites from p. B-31, Figure 2 in Blahnik (1971)				
Material	Site	Name	Location	Geology
Mare materials	1	SW Oceanus Procellarum	2° S, 38° W	Mare material
	2	Sulpicius Gallus	2. 1° N, 11° E	Dark mantle material
Circumbasin materials	3	West of Riccioli	0° N, 80° W	Hevelius Formation (Orientale ejecta)
	4	South of Vallis Alpes	47° N, 7° E	Alpes Formation (Imbrium ejecta)
	5	West of Janssen	42° S, 34° E	Janssen Formation (Nectaris ejecta)
	6	NE of Proclus	17° N, 49° E	Crisium basin rim
Highland plains, plateau and dome materials	7	Theophilus floor	12° S, 27° E	Plains material, large crater floor
	8	Mons Gruithuisen Delta	36° N, 39° W	Highland dome material
	9	East of Cayley	4° N, 15° E	Highland plains material
	10	NW of Mersenius	19° S, 52° W	Hilly and furrowed material
	11	East of Cruger	18° S, 62° W	Hilly and pitted material
	12	North of Spallanzani	45° S, 23° E	Plains material
Typical highlands	13	East of Mersenius	22° S, 45° W	Highlands*
	14	(not located)		
Crater materials	15	Tycho	42° S, 12° W	Young crater
	16	Not located		Crater chain, smooth-rimmed crater
	17	NW of Bohnenberger	14° S, 38° E	Crater materials*
* Note: these locations do not match the description well and may be mislocated in the source document.				

Benjamin, P. and Head, J. W., 1970. LRV design evaluation traverses - cases 320 and 340. Bellcomm Inc. Memorandum B70-01016, 13 January 1970.

Blahnik, J. E., 1971. Automated lunar exploration study. Report no. M-29, prepared for the Apollo Lunar Exploration Office under contract NASW-2139. Cicago: Astro Sciences, IIT Research Institute, December 1971.

Head, J. W., 1970. Geologic Characteristics of Lade, a Possible Apollo Highland Landing Site. Bellcomm memorandum B70 07080 (NASA-CR-109970), 24 July 1970.



1971: Lunar Base Synthesis Study

Blahnik (1971) described plans for continuing exploration with reduced NASA funding. At the other end of the scale, the Lunar Base Synthesis Study described what might be possible with increased funding. This expanded exploration program would have required financial resources greatly exceeding anything likely to be available.

The Lunar Base Synthesis Study was performed by North American Rockwell for NASA's Marshall Space Flight Center (Carpenter *et al.* 1971a, b). It was intended to help define the role a base or outpost might have in regional exploration of the Moon. It assumed an exploration mission lasting from two to five years, possibly supported by a small space station in lunar orbit. Surface modules might be derived from components used in an Earth-orbiting space station. As part of the study, several areas in which a base might be situated were considered (Figure 219). In each area numerous science targets were identified and used to plan surface traverses and operations, including the use of flying vehicles and surface rovers.

The areas and the traverses described in this study are shown in Figures 219 to 224. The various science targets in each area are described in Tables 64 to 74. Each of the many targets would have its own local activity plan, and one at Schröter's valley was illustrated schematically in the report as an example (Figure 219B).

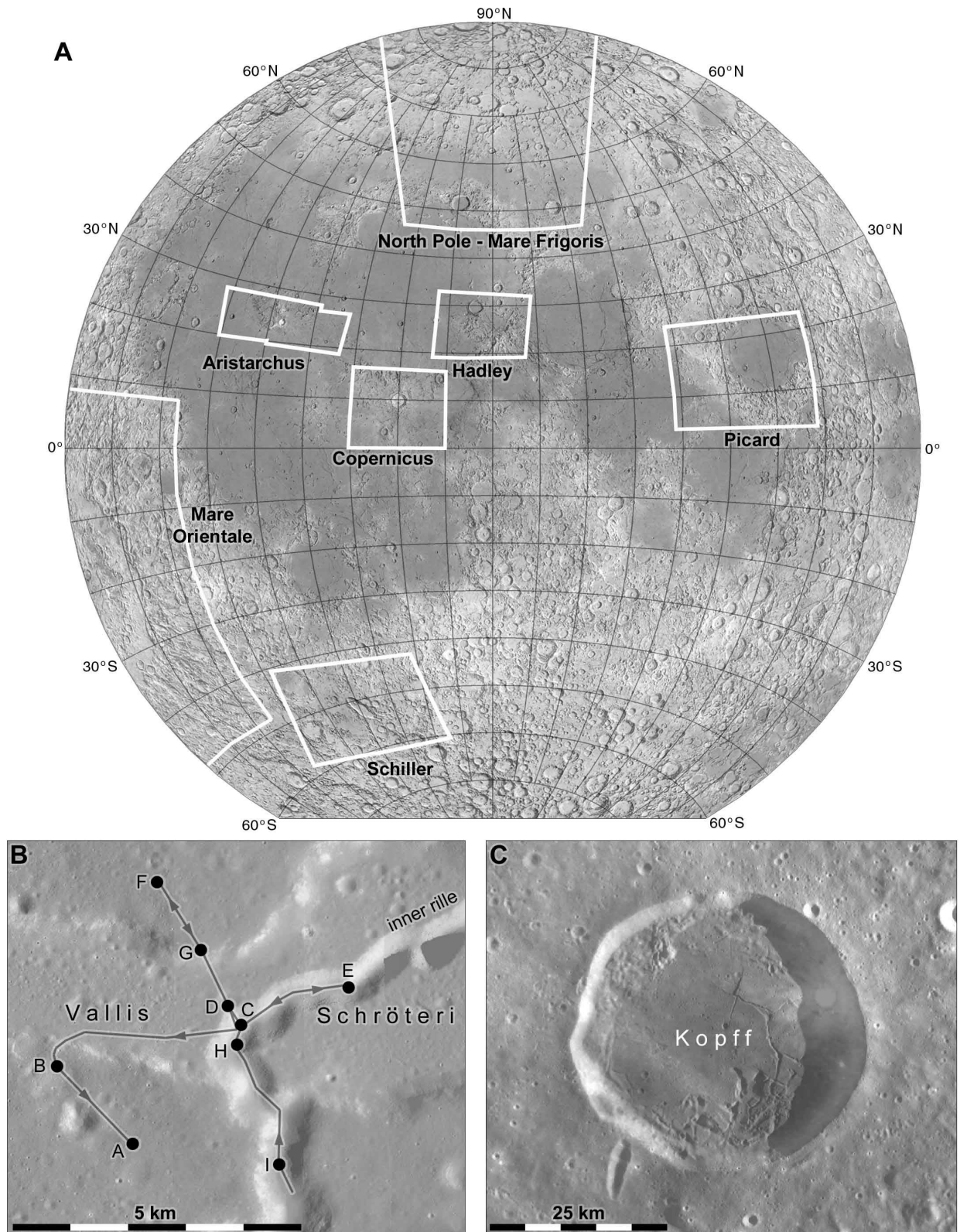


Figure 219. Lunar Base Synthesis Study. A: Exploration regions on the nearside from the Synthesis study. B: Detail of activities at Aristarchus site 8 (Figure 223). C: An observatory would be set up at an unidentified location on the floor of Kopff crater in the Orientale basin.

Table 65. Synthesis Study Activities at Mare Frigoris, Primary Sites		
Site	Location	Notes
C1	52.5° N, 0.5° E	Centroid of first level or primary sites
Base	59.0° N, 1.5° E	Possible base location, centroid of all sites (but Frigoris may need two base sites)
1	55.0° N, 6.0° E	Crater chain in Mare Frigoris, 18-40 hours
2	53.0° N, 6.0° E	Highland inliers in Mare Frigoris, 18-40 hours
3	52.0° N, 4.0° E	Rima Archytas and mare boundary, 18-48 hours
4	50.0° N, 6.5° E	Head of Alpine valley, search for evidence of origin, 30-200 hours
5	49.0° N, 9.0° E	Egede, polygonal crater with breached wall, 20-48 hours, then start traverse
6	48.7° N, 11.0° E	Geophysical traverse across Egede ending on the rim (site 6), 4-12 hours at site 6
7	47.0° N, 14.0° E	Floor of depression or degraded crater north of Eudoxus, 16-150 hours
8	46.0° N, 12.0° E	Small craters on the rim of the ring structure, possibly volcanic, 6-18 hours
9	50.0° N, 16.0° E	Aristoteles floor structures and materials, 6-18 hours
10	51.0° N, 16.0° E	Aristoteles walls and terraces, 6-36 hours
11	51.5° N, 15.0° E	Coarse crater rim material, 6-12 hours
12	53.0° N, 13.5° E	Braided texture, possible base surge deposits, 6-12 hours
13	54.5° N, 15.0° E	Rima Aristoteles I, mare stratigraphy, ejecta, instrument station, 40-120 hours
14	49.0° N, 2.0° E	Alpine Valley and Alpine highlands, 16-48 hours
15	47.0° N, 1.0° W	Junction of Alpine Valley and Mare Imbrium, 18-60 hours
16	45.0° N, 5.0° W	Traverse from 15 to 16, perpendicular to mare and mascon boundary, 110 km
17	46.0° N, 1.0° W	Geophysical traverse perpendicular to above, 55 km
18	47.5° N, 3.0° W	
19	46.3° N, 7.0° W	Wrinkle ridge, rim of 'ghost' crater, 18-40 hours
20	48.5° N, 11.0° W	Traverse from 19 to 20 across ghost crater, 110 km
21	46.0° N, 9.0° W	Mons Pico, Imbrium basin inner ring mountain, 12-48 hours
22	46.5° N, 12.0° W	mare material, Mare Imbrium, 12-30 hours
23	48.0° N, 13.0° W	Teneriffe Mountains, highland inliers, possible transient activity, 12-25 hours
24	48.0° N, 16.0° W	Marginal rilles, wrinkle ridges, seismic instrument station, 18-36 hours
25	50.0° N, 13.5° W	Traverse across edge of basin, 110 km, 24 to 25, then 36-120 hours at sinuous rille
26	51.0° N, 12.5° W	Outer rim of Plato, sinuous rille source, structure, stratigraphy, 30-150 hours
27	51.5° N, 12.0° W	Inner walls and floor of Plato, 13-25 hours
28	51.3° N, 10.0° W	Traverse from 27 to 28 and 29 across floor of Plato, to centre of crater and then to
29	53.0° N, 9.5° W	northern rim
30	50.2° N, 3.0° W	Rima Plato II, rilles and highland stratigraphy, 1 to 6 stops, each 18-45 hours
31	52.5° N, 3.0° W	Rima Plato I, rille and tectonic structures, 18-45 hours
32	55.0° N, 5.0° W	Hills north of Montes Alpes, rocks and structures, 6-18 hours, then traverse to 33
33	59.0° N, 2.0° W	Stop on geophysical traverse across Mare Frigoris, wrinkle ridges, 13-19 hours
34	62.0° N, 1.0° E	Archytas-Bond rim, geophysical instrument station, highlands, 16-50 hours
35	60.5° N, 3.5° E	Geophysical traverse from 34 across subdued crater, alternate instrument station site
36	58.7° N, 5.0° E	Archytas, young crater with central peak, 12-38 hours
36a	56.0° N, 7.0° E	Protagoras, young crater with central peak, 12-38 hours
37	54.5° N, 1.0° E	Intersection of mare-mountain contact, Rima Archytas I, crater chain, 40-80 hours

From these operational plans the requirements for EVA time, total drive distance and equipment needs could be estimated, and the optimum location for the base could be found. Bases would usually be located to minimize travel requirements, roughly at the centroid of the science targets. For most sites a base location was suggested, but at Mare Orientale and Mare Frigoris targets were divided into primary and secondary groups and centroids were found for both sets of targets in each region. At Orientale the two centroids were fairly close (Figure 221, Tables 66, 67 and 68), so the centroid of all the targets combined was also found and might make a suitable base location.

Table 66. Synthesis Study Activities at Mare Frigoris, Alternative Sites		
Site	Location	Notes
C2	79.0° N, 13.0° W	Centroid of secondary or alternative sites
38	63.0° N, 1.0° W	Timaeus crater, central peak, walls nearly breached, 6-18 hours
39	65.3° N, 0.0° W	W. Bond, ancient or subdued crater, considered a possible caldera, 18-30 hours
40	73.4° N, 10.0° W	Anaxagoras, crater with bright rays and elongated central peak, 12-75 hours
41	74.5° N, 17.0° W	Anaxagoras crater ray material and ejecta base surge study, 6-18 hours
42	73.2° N, 8.0° W	Geophysical traverse at Goldschmidt crater, starting at the rim of Anaxagoras, ending near contact of Goldschmidt and Barrow craters
43	73.0° N, 2.0° E	
44	78.0° N, 14.0° E	Scoresby, symmetrical crater, central peak, highlands, 12-37 hours
45	80.0° N, 10.0° E	Ridge forming common rim between Main and Challis twin craters, 12-30 hours
46	83.0° N, 20.0° W	N-S tectonic structures, possible permanent shadow areas, 24-80 hours
47	86.5° N, 2.0° W	Linear segment of Byrd crater rim, 20-60 hours
48	87.7° N, 30.0° E	Peary crater rim, permanently shaded small crater, 30-100 hours
49	90.0° N	North Pole, rim of Peary, 50-200 hours
50	88.6° N, 40.0° W	Tectonic structures, deep shaded crater, 20-40 hours
51	73.5° N, 28.0° W	Philolaus D - transient phenomenon site, tectonic structures, 18-40 hours
52	72.5° N, 32.0° W	Philolaus crater floor and central peak, 12-20 hours
53	71.0° N, 35.0° W	Crater wall and rim, slump terraces, 12-20 hours

At Frigoris the primary sites clustered around Plato and the secondary sites extended to the north pole, with their separate centroids far apart. When all targets were considered together the centroid was not very suited to either primary or secondary targets, suggesting that two separate bases might be necessary here for adequate regional exploration.

The Synthesis Study also considered a possible astronomical observatory. A typical layout including a shelter for astronauts, and optical, X ray and radio instruments including large radio arrays would require a substantial flat area for deployment, on the order of 30 by 60 km across. One site illustrated was the floor of Kopff crater on the edge of Mare Orientale (Figure 211C), though this site was smaller than desired. The limb location would minimize scattered light from Earth and allow radio observations from regions hidden from Earth to reduce terrestrial interference.

When this study was being prepared, the Apollo 15 landing site was expected to be at the south end of Rima Hadley. Site 1 at Hadley (Figure 223, Table 72) was the anticipated Apollo target.

Table 67. Synthesis Study Activities, Mare Orientale First Level Remote Sites

Site	Location	Notes
C1	15.5° S, 89.5° W	Centroid of first level (primary) remote sites
Base	17.5° S, 88.0° W	Centroid of all (primary plus secondary) sites, in hills east of Kopff crater
1	20.0° S, 95.0° W	Central mare, wrinkle ridge, hills (basin central peaks?), 27-85 hours
2	22.0° S, 95.5° W	Inlier, subsidence ring, mare and pre-mare stratigraphy, 25-70 hours
3	22.5° S, 96.5° W	Open fissure in mare, stratigraphic section, 13-30 hours
4	17.7° S, 94.5° W	Hohmann, possible maar-type crater, 4-16 hours
5	16.7° S, 95.0° W	Outer crater ejecta, base surge deposits, secondary craters, 12-18 hours
6	15.7° S, 95.0° W	Smooth surface crater deposits, 6-12 hours
7	15.0° S, 94.0° W	Maunder, very young impact crater, rim and inner wall stratigraphy, 12-24 hours
8	14.5° S, 93.5° W	Young impact crater, central peak and crater floor, 6-50 hours
9	19.5° S, 92.5° W	Open fissures in mare, study stratigraphy, 18-50 hours
10	17.5° S, 91.0° W	Montes Rook Formation west of Kopff crater, hummocky material, 12-48 hours
11	18.0° S, 90.0° W	Long gash in Kopff crater rim, smooth rim deposits, 12-36 hours
12	17.0° S, 90.4° W	Rim and walls of Kopff, possible volcanic crater, 12-36 hours
13	17.5° S, 89.5° W	Kopff, fractured crater floor, 6-36 hours
14	14.5° S, 88.7° W	Radial and N-S rifts, central basin plains, 24-48 hours
15	13.5° S, 88.0° W	Lacus Veris and concentric faults, downfaulted ring, 12-36 hours
16	12.0° S, 87.5° W	Pre-Orientale highland material in mountains, inner Rook ring, 16-48 hours
17	10.0° S, 86.5° W	End of Lacus Veris and surrounding pre-Orientale highlands, 16-60 hours
18	9.0° S, 85.5° W	Montes Rook Formation, hummocky outer ring, 16-60 hours
19	8.0° S, 84.0° W	Cordillera scarp and materials, stratigraphy and structure, 16-60 hours
20	7.2° S, 83.0° W	Schlüter crater rim and wall material, 18-80 hours
21	6.0° S, 83.5° W	Schlüter crater central peak and floor, possible recent activity, 16-80 hours
22	6.0° S, 81.0° W	Hartwig, old crater mantled with Orientale ejecta, 16-24 hours
23	3.5° S, 79.5° W	Orientale ejecta (Cordillera Formation) with braided texture, 8-16 hours
24	14.0° S, 87.0° W	Lacus Veris, edge of one of the dark lava patches, 16-36 hours
25	15.7° S, 86.0° W	Central basin plains, concentric fault, Lacus Veris contact, 26-40 hours
26	17.0° S, 86.5° W	Fractured lobate hill in Inner Rook hills east of Kopff, 8-24 hours
27	18.0° S, 85.0° W	Domes, possible inliers, in Lacus Veris, 8-24 hours
28	19.2° S, 86.0° W	Crater containing circular ridge pattern or flow, 8-24 hours
29	20.0° S, 85.5° W	Mountain of pre-Orientale material, 8-24 hours
30	11.0° S, 95.5° W	Inner ring mountains, northern section, 8-24 hours
31	10.5° S, 87.0° W	Dark halo crater in western Lacus Veris, 8-24 hours
32	9.0° S, 98.0° W	Montes Rook, fault scarp, pre-Orientale or Montes Rook stratigraphy, 24-48 hours
33	9.5° S, 96.5° W	Sinuous rille, stratigraphy, rille origin, geophysics, 48-200 hours
34	22.0° S, 92.0° W	Central mare and fresh crater, 16-24 hours
35	23.0° S, 90.2° W	Innermost Montes Rook fault scarp, hummocky material, 8-24 hours
36	23.5° S, 89.3° W	Fractured terrain of Inner Rook range, trafficability nearly impossible, 12-36 hours

Note: the feature now called Lacus Veris was referred to as Mare Veris in this document

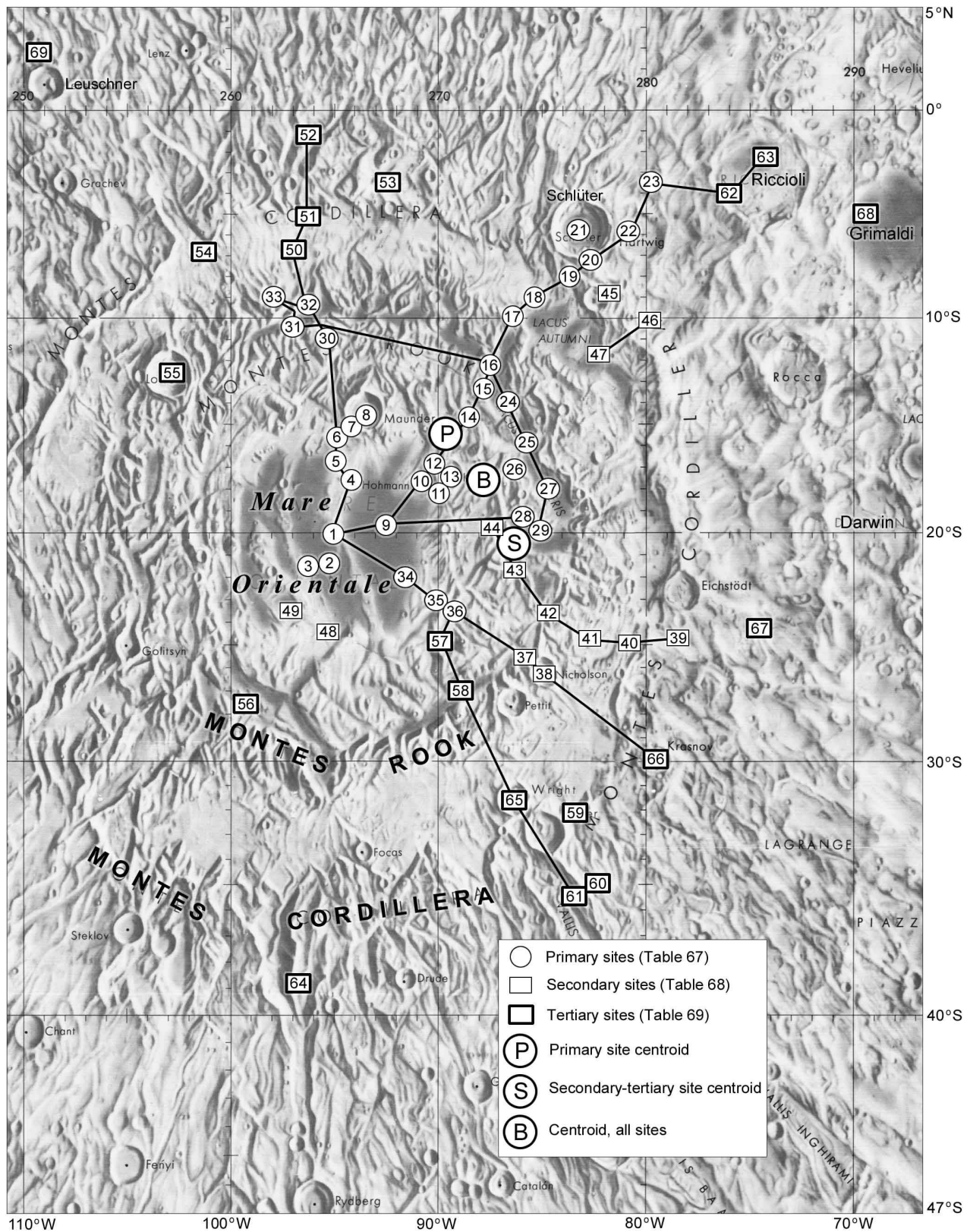


Figure 221. Lunar Base Synthesis Study. Activities in the Mare Orientale region, extending onto the farside. The base map is a composite of contemporary U.S. Air Force charts (ACIC 1976a; 1976b).

Table 68. Synthesis Study Activities, Mare Orientale Second Level Remote Sites

Site	Location	Notes
C2	20.5° S, 86.5° W	Centroid of alternative or secondary (second and third level) remote sites
37	25.5° S, 86.0° W	Veris fault scarp, Montes Rook, contacts between various units, 160-250 hours
38	26.0° S, 85.0° W	Wright B (now Nicholson), possible volcanic crater, interior and walls, 20-80 hours
39	24.5° S, 78.5° W	Cordillera Formation, textured surface, Eichstädt E, 20-80 hours
40	25.0° S, 81.0° W	Cordillera scarp, stratigraphy of Cordillera and older rocks, 24-56 hours
41	24.5° S, 83.0° W	Montes Rook Formation, chaotic terrain, 8-16 hours
42	23.5° S, 85.0° W	Veris fault scarp, Montes Rook and older stratigraphy, 16-25 hours
43	21.5° S, 87.0° W	Small sinuous rille in southern Lacus Veris, 36-200 hours
44	19.7° S, 87.5° W	Inner Montes Rook scarp, pre-Rook stratigraphy, 8-24 hours
45	8.7° S, 81.5° W	Schlüter A crater, northeast rim, 8-40 hours
46	10.0° S, 80.0° W	Lineated and patterned surface of Cordillera Formation, 20-80 hours
47	12.0° S, 82.5° W	Gentle slope across Cordillera scarp, slumping, edge of Lacus Autumni, 16-60 hours
48	24.5° S, 95.5° W	Deep fractures bordering Mare Orientale, 13-30 hours
49	23.5° S, 97.3° W	Border graben complex and edge of Mare Orientale, 25-65 hours

Table 69. Synthesis Study Activities, Mare Orientale Third Level Remote Sites

Site	Location	Notes
50	6.5° S, 97.0° W	Outer part of Montes Rook Formation, 12-50 hours
51	5.0° S, 96.5° W	Cordillera scarp, Cordillera Formation and older stratigraphy, 8-80 hours
52	1.2° S, 96.5° W	Cordillera Formation with chevron pattern, base surge study, 12-24 hours
53	3.5° S, 92.5° W	Montes Rook contact area, geophysics and stratigraphy, 8-24 hours
54	6.7° S, 101.0° W	Intersection of NW-trending fault with Cordillera scarp, mare contact, 28-90 hours
55	12.5° S, 103.0° W	Lowell, far side central peak crater on basin ring, 12-40 hours
56	27.5° S, 99.5° W	Faulted pre-Orientale crater, old high mountain scarp, 16-40 hours
57	25.7° S, 90.0° W	Highly fractured material, 12-24 hours
58	27.0° S, 89.0° W	Central basin plains and middle Rook fault scarp, 16-24 hours
59	32.2° S, 84.0° W	Cordillera scarp, southeast border of outer ring, 24-56 hours
60	35.0° S, 83.0° W	Cordillera deposits, outer basin rim, 20-80 hours
61	35.5° S, 84.0° W	Bouvard-Vallis Baade, major basin-radial structure, 40-160 hours
62	4.0° S, 76.0° W	Riccioli crater walls, old crater, partly mantled, 16-40 hours
63	2.3° S, 74.4° W	Riccioli floor, basalt and outer Orientale ejecta deposits, 16-80 hours
64	38.7° S, 97.0° W	Major basin-radial rift, 40-140 hours
65	31.5° S, 87.0° W	Wright crater, interior domes, 20-80 hours
66	30.0° S, 79.5° W	Krasnov crater and central peak, 16-48 hours
67	24.5° S, 75.0° W	Lamarck D, outer part of Cordillera Formation, 16-80 hours
68	5.0° S, 69.5° W	Grimaldi rim and basalt floor, 16-65 hours
69	3.0° N, 109.5° W	Major basin radial crater chain, 40-120 hours

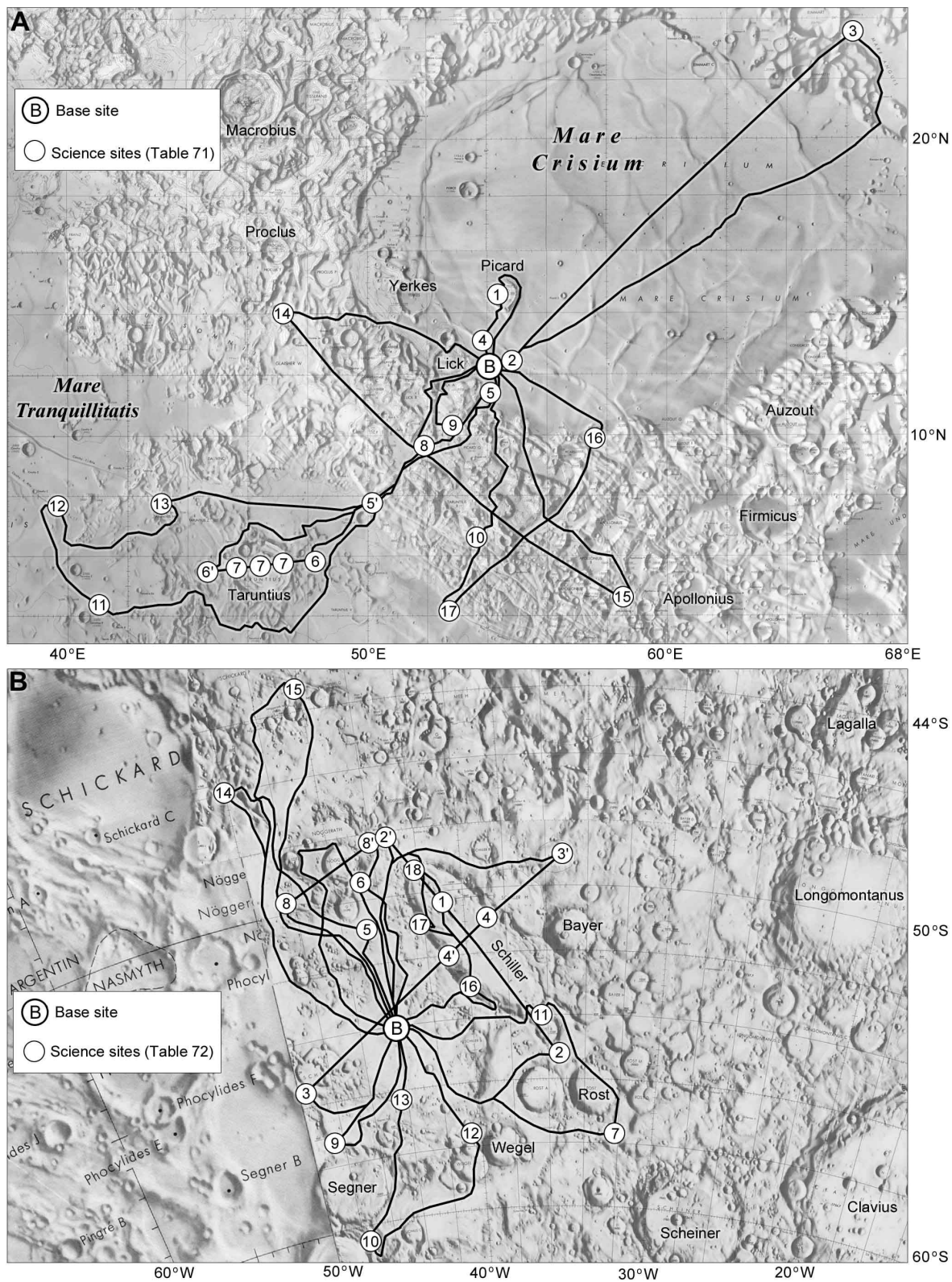


Figure 222. Lunar Base Synthesis Study. Activities in the Picard-Mare Crisium region (A) and near Schiller (B). The base maps are composites of contemporary ACIC LAC and global maps (A: LAC 43, 44, 61 and 62. B: LAC 110, 125 and ACIC (1970)).

Table 70. Synthesis Study Traverses at Mare Orientale

First Level		Second Level	
Traverse	Sites	Traverse	Sites
T1	1, 9, 10, 12, 14, 15, 16, 17, 18, 19, 20, 22, 23	T4	39, 40, 41, 42, 43, 44
		T5	46, 47
T2	1, 4, 5, 6, 30, 33	T6	29, 27, 25, 24, 16, 31
T3	1, 9, 28, 29	T7	1, 34, 35, 36, 37, 38, 66
		T8	1, 34, 35, 36, 57, 58, 65, 61
		T9	33, 50, 51, 52 (continuation of T2)
		T10	23, 62, 63 (continuation of T1)

Table 71. Synthesis Study Activities at Picard

Site	Location	Notes
Base	12.3° N, 54.1° E	Mare Crisium, east of Lick, south of Picard
1	14.5° N, 54.3° E	Floor of Picard, asymmetric double crater with central peak, 20-60 hours
2	12.3° N, 54.7° E	Mare Crisium, linear rille terminating at craters, 18-50 hours
3	23.7° N, 66.1° E	Geophysical traverse from 2 to 3 across Mare Crisium mascon, 5 minute stop each 2 km for geophysical data, seismic studies at selected sites on return to base, 4 hours each, instrument station at mid-traverse. Station 3 is in Mare Anguis near Eimmart
4	13.0° N, 53.9° E	Concentric faults, 36-80 hours
5	11.2° N, 54.1° E	Geophysical traverse across basin rim, 5 minute stop every 1 km for geophysical data, seismic studies at 3 selected sites on return trip
5'	7.8° N, 50.1° E	
6	5.5° N, 44.8° E	Geophysical traverse across Taruntius crater, 5 minute stop every 2 km for geophysical data, investigate crater walls and central peak at site 7 locations
6'	5.9° N, 48.2° E	
7	(three stops)	Taruntius concentric inner structures and central peak, 3 stops, 50-200 hours each
8	9.5° N, 51.9° E	Irregular depressions among hills on Crisium rim, 60-200 hours
9	10.2° N, 52.9° E	Structures radial to Crisium, 30-100 hours
10	6.5° N, 53.5° E	Ridges and rilles concentric to Crisium, 30-100 hours
11	4.3° N, 41.1° E	Crater chain in Mare Tranquillitatis, 30-60 hours
12	7.6° N, 39.7° E	Cauchy rille, fault scarp, 50-75 hours, this optional site may be explored robotically
13	7.7° N, 43.0° E	Intersection of old crater Taruntius M and Cauchy 1 rille, 24-80 hours
14	14.0° N, 47.2° E	Low relief highland geophysical instrument station, 6-12 hours
14-15	(traverse)	Geophysical traverse between instrument stations at sites 14 and 15, stops every 5 km for gravity and magnetic data, return as needed for local seismic data
15	4.5° N, 58.5° E	Highland geophysical instrument station west of Apollonius, 6-40 hours
16	9.9° N, 57.6° E	Geophysical traverse across basin rim structures, 5 minute stops at unspecified intervals for data, stops at 3 selected sites for seismic data on return trip
17	4.1° N, 52.7° E	

Table 72. Synthesis Study Activities at Schiller		
Site	Location	Notes
Base	54.0° S, 44.0° W	West of Schiller on old basin floor plains
1	50.3° S, 41.0° W	Schiller interior and median ridge
2	55.2° S, 35.4° W	Geophysical traverse across Schiller's long dimension, seismic data and drilling at 4 sites, stops every 3 km for gravity, magnetic data, every 1 km at local anomalies
2'	48.2° S, 43.4° W	
3	55.5° S, 49.6° W	Geophysical traverse across Schiller's short dimension, seismic data and drilling at 2 sites, stops as above, instrument station deployed at each end
3'	49.0° S, 35.2° W	
4	52.0° S, 41.1° W	Schiller crater walls, 6-60 hours at each of 2 sites along the 3-3' traverse
4'	50.9° S, 38.9° W	
5	50.9° S, 45.0° W	Irregular ridges, 18-30 hours
6	49.4° S, 44.9° W	Noggerath crater rim, faults, drilling, 100-250 hours
7	57.8° S, 32.1° W	Pre-Imbrian hills south of Rost crater, 80-150 hours for geological study
8	49.7° S, 48.5° W	Geophysical traverse across Noggerath crater, seismic studies and drilling at 4 sites, 28 hours at each site, stops every 1 km for gravity and magnetic data
8'	48.2° S, 44.0° W	
9	57.3° S, 48.6° W	Sinuuous ridge at the north rim of Segner crater, 50-250 hours
10	60.6° S, 47.5° W	Slump features on outer rim of Zuchius, 12-36 hours
11	54.0° S, 36.5° W	Extension of Schiller into Rost B crater, investigate alignment, 48-150 hours
12	57.6° S, 40.4° W	Weigel D, possible tectonic structure, 36-150 hours
13	56.2° S, 44.3° W	Northwest-trending linear feature (secondary craters) in Schiller basin, 36-65 hours
14	45.9° S, 50.0° W	Fault scarp on rim of Schickard, 60-200 hours
15	43.3° S, 46.1° W	Tectonic structures west of Drebel G, 80-250 hours
16	53.0° S, 41.0° W	Crater wall, west side of Schiller, 6-60 hours
17	50.9° S, 42.0° W	Crater wall, west side of Schiller, 6-60 hours
18	49.2° S, 42.2° W	Crater wall, west side of Schiller, 6-60 hours

Table 73. Synthesis Study Activities at Hadley

Site	Location	Notes
Base	27.0° N, 1.5° E	Palus Putredinis, northwest of Apollo 15 site
1	24.8° N, 2.3° E	Rima Hadley, source of sinuous rille, then a possible Apollo 15 site, 20-200 hours
2	26.2° N, 3.1° E	Rima Hadley termination, base of Hill 305 (Apollo 15 name), 48-250 hours
3	25.9° N, 4.5° E	Mount Hadley, Apennine Mountains, traverse up valley from site 2, 60-200 hours
4	25.2° N, 2.2° E	Ridge west of Apennine Front and Rima Hadley, 20-60 hours
5	27.5° N, 4.2° E 26.4° N, 5.1° E	Linear ridges and fractures in the Apennine Mountains, 2 sites north and east of Mount Hadley, 40-140 hours
6	30.8° N, 6.7° E	South end of Caucasus Mountains, geology and structure, 10-60 hours
7	32.1° N, 7.4° E	Fault in the Caucasus Mountains, 10-60 hours
8	27.0° N, 1.5° E	NW Mare Serenitatis, rocks and stratigraphy, 80-230 hours
9	29.0° N, 6.6° E	Palus Putredinis, rocks and stratigraphy, 80-230 hours
10	24.5° N, 0.1° E 26.4° N, 2.5° W 27.4° N, 2.8° E	Linear rilles (graben) on the Apennine Bench, 3 sites at Rima Bradley, Rima Archimedes III and Rima Fresnel II , 80-200 hours at each site
11	28.0° N, 2.2° W	Geophysical traverse across small mascon, stop every 1 km, seismic station at 11, geophysical station at 11' (SE end of traverse), 50-70 hours for drilling at 11 and 11'
11'	25.6° N, 1.1° E	
12	24.0° N, 3.9° E	Continue traverse from 11' to Apennine Front, short stops at 1 km intervals
13	22.9° N, 4.9° W	Negative gravity anomaly in SE Mare Imbrium, short stops at 1 km intervals, instruments at SW end, 30 m drill holes, seismic sites at 13 and 13', 40-240 hours.
13'	20.0° N, 9.9° W	
14	21.8° N, 2.0° E 23.6° N, 4.6° E	Conon and Aratus craters, 28-60 hours for 2 sites
15	28.6° N, 3.9° W 29.5° N, 2.5° W	Archimedes crater rim and floor, 12-60 hours for 2 or more sites
16	30.0° N, 1.0° E 31.0° N, 1.3° E	Autolycus crater rim and interior, 12-60 hours for 2 or more sites
17	28.0° N, 5.0° W 27.6° N, 5.9° W	Traverse across fault scarp and lineaments, 28-60 hours for 2 sites, may be robotic
18	31.3° N, 6.2° W	Geophysical traverse across Archimedes, activities as for traverse 11-11'
18'	28.1° N, 2.6° W	
19	30.0° N, 4.0° W	Archimedes crater floor, 6-12 hours
20	30.8° N, 4.6° W	Archimedes northwest wall, 18-60 hours

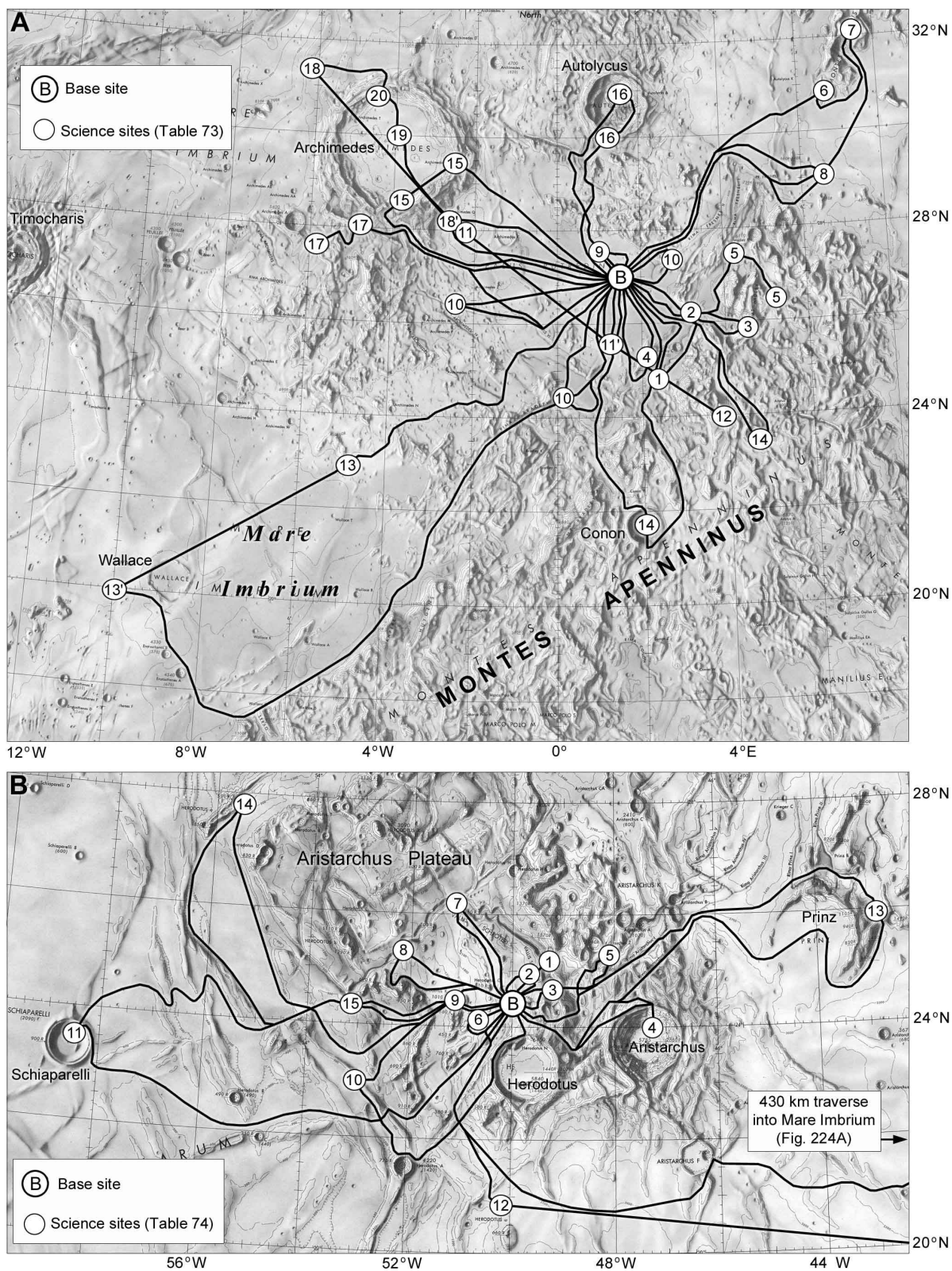


Figure 223. Lunar Base Synthesis Study. Activities in the Hadley region (top) and Aristarchus region (bottom). The base maps are composites of contemporary ACIC LAC maps (A: LAC 40, 41. B: LAC 38, 39). An extension of the Aristarchus map to the east is shown in Figure 224A.

Table 74. Synthesis Study Activities at Aristarchus		
Site	Location	Notes
Base	24.4° N, 50.0° W	North of Herodotus, west of Cobra Head
1	25.1° N, 49.4° W	Schröter's Valley, 36-300 hours, stratigraphy, wall mapping, inner and outer rille
2	24.9° N, 49.7° W	Aristarchus Plateau west of Schröter's Valley, minimum 48 hours
3	24.7° N, 49.2° W	Cobra Head and adjacent plateau, up to 250 hours, geology, instrument deployment
4	24.0° N, 47.3° W	Aristarchus crater, 40-200 hours including one night sortie.
5	25.3° N, 48.1° W	Aristarchus hills north of crater, 80-400 hours among hills and rilles
6	24.1° N, 50.7° W	Aristarchus Plateau, elongated domes, 80-150 hours, drilling and surface studies
7	26.2° N, 51.1° W	Central part of Schröter's Valley, 28-100 hours
8	25.3° N, 52.1° W	Lower part of Schröter's Valley, 28-100 hours (Figure 219B)
9	24.3° N, 51.0° W	Faulted area, irregular depressions, 40-200 hours
10	23.0° N, 53.0° W	Wrinkle ridges and faults, 24-40 hours
11	23.5° N, 58.5° W	Schiaparelli, crater with inner ring, possibly volcanic, minimum 12 hours
12	20.8° N, 50.1° W	Geophysical traverse across a mascon, from site 12 to site 12', 430 km one way, at 3 km/hour, seismic studies at 3 sites, gravity and magnetic data every 1 km.
12'	18.4° N, 34.8° W	
13	25.9° N, 42.9° W	Prinz, ancient crater and hills, pre-Imbrian material, 18-200 hours
14	27.9° N, 55.5° W	Elongated craters, depressions, wrinkle ridges, 18-30 hours
15	24.2° N, 53.1° W	Faults and end of Schröter's Valley, 24-200 hours, may include drilling
Note: Traverses on the plateau and in Schröter's Valley at sites 3, 7 and 8 might use robotic rovers		

Table 74. Synthesis Study Activities at Copernicus		
Site	Location	Notes
Base	10.5° N, 17.8° W	Outer eastern flank of Copernicus
1	9.75° N, 16.8° W	Geophysical traverse across Copernicus, site 1 to site 2, stops every 1 km, seismic study and drilling at two sites, deploy instruments on central peak and at Site 2.
2	9.4° N, 29.5° W	
3	15.4° N, 26.9° W	Irregular fault valley, 50-200 hours
4	12.5° N, 25.7° W	Tobias Mayer C, 20-80 hours.
5	7.2° N, 27.7° W	Domes north of Hortensius, 50-200 hours
6	5.7° N, 26.4° W	Linear, diverging ridges, 20-60 hours
7	1.75° N, 22.2° W	Peak on south side of Reinhold crater ejecta, 30-80 hours
8	1.1° N, 15.9° W	Gambart, hexagonal crater, tectonic features to the west, 25-75 hours
9	2.3° N, 10.3° W	Gambart BA, circular crater with sinuous ridges, 25-75 hours
10	4.5° N, 11.2° W	Traverse across bifurcated mare ridge, from site 10 to site 10', with 8 stops for terrain study
10'	5.0° N, 13.8° W	
11	9.75° N, 12.8° W	Crater chain, 30-80 hours
12	12.5° N, 13.7° W	Geophysical traverse across Eratosthenes from site 12 to site 12', with stops every 5 km, seismic study at two sites, 80-200 hours
12'	15.2° N, 10.1° W	
13	12.7° N, 15.7° W	Crater chain, 80-250 hours
14	15.4° N, 16.8° W	Rima Stadius crater chain, 12-150 hours
15	13.8° N, 16.2° W	Intersection of N-S and NW trending rift valleys, 75-225 hours
16	14.8° N, 19.8° W	Rima Stadius II, 12-100 hours
17	10.5° N, 19.0° W	Copernicus walls, 42-100 hours, four sites

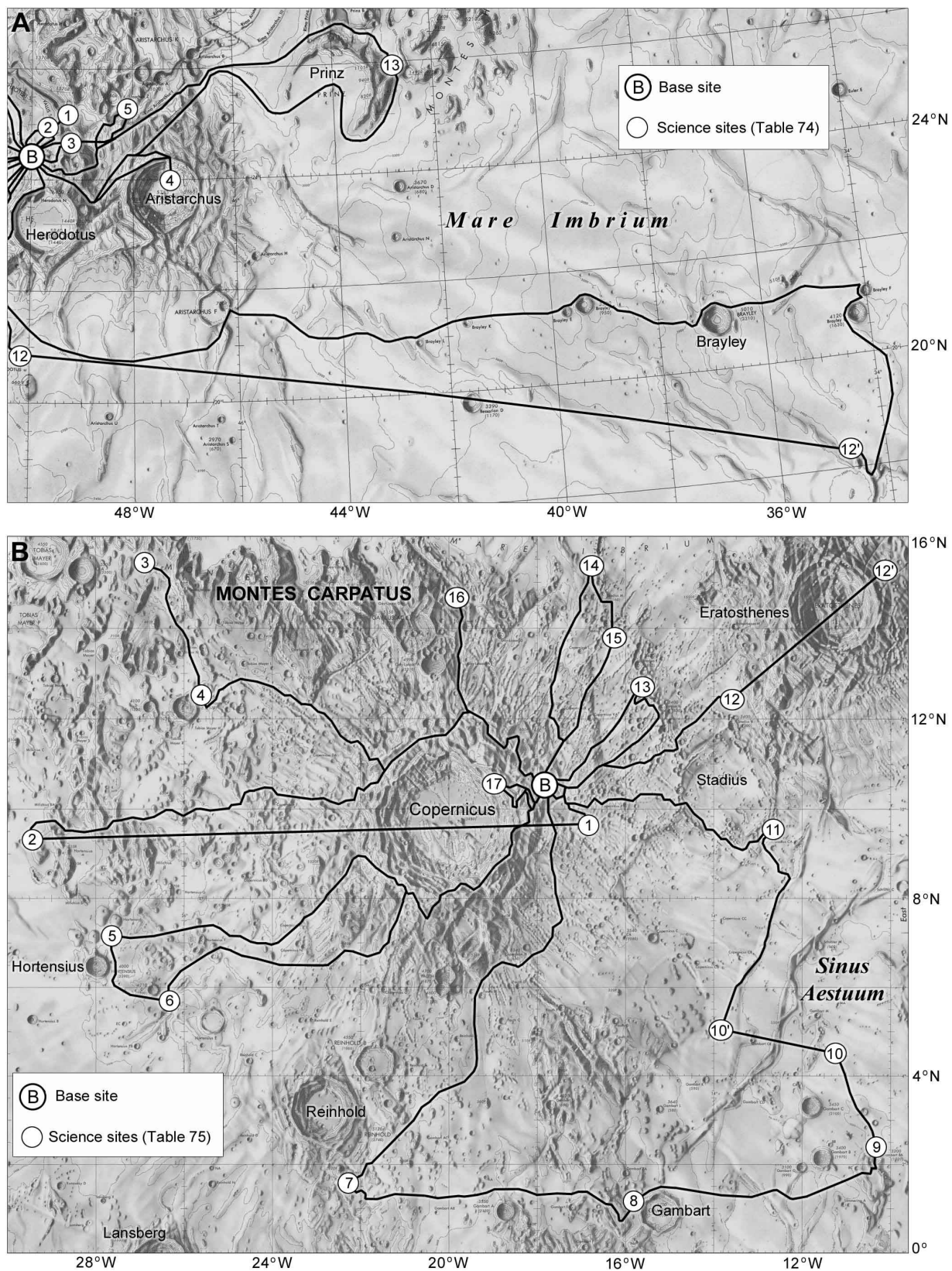


Figure 224. Lunar Base Synthesis Study. A: Activities east of Aristarchus, continued from Figure 223B. B: Activities near Copernicus. Maps are contemporary ACIC LAC sheets (A: LAC 38, 39. B: LAC 58).

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Table A1. Spacecraft locations on the Moon, from this volume.			
Spacecraft	Date of contact	Location	Event
Apollo 13 - SIVB upper stage	14 April 1970	2.553° S, 27.887° W	Impact
Luna 16	20 September 1970	0.513° S, 56.364° E	Landing
Luna 17 - Lunokhod 1, end of drive	17 November 1970 14 September 1971	38.238° N, 34.997° W 38.316° N, 35.004° W	Landing Drive
Apollo 14 - SIVB upper stage - LM ascent stage	5 February 1971 4 February 1971 8 February 1971	3.646° S, 17.472° W 8.179° S, 26.031° W 3.420° S, 19.637° W	Landing Impact Impact

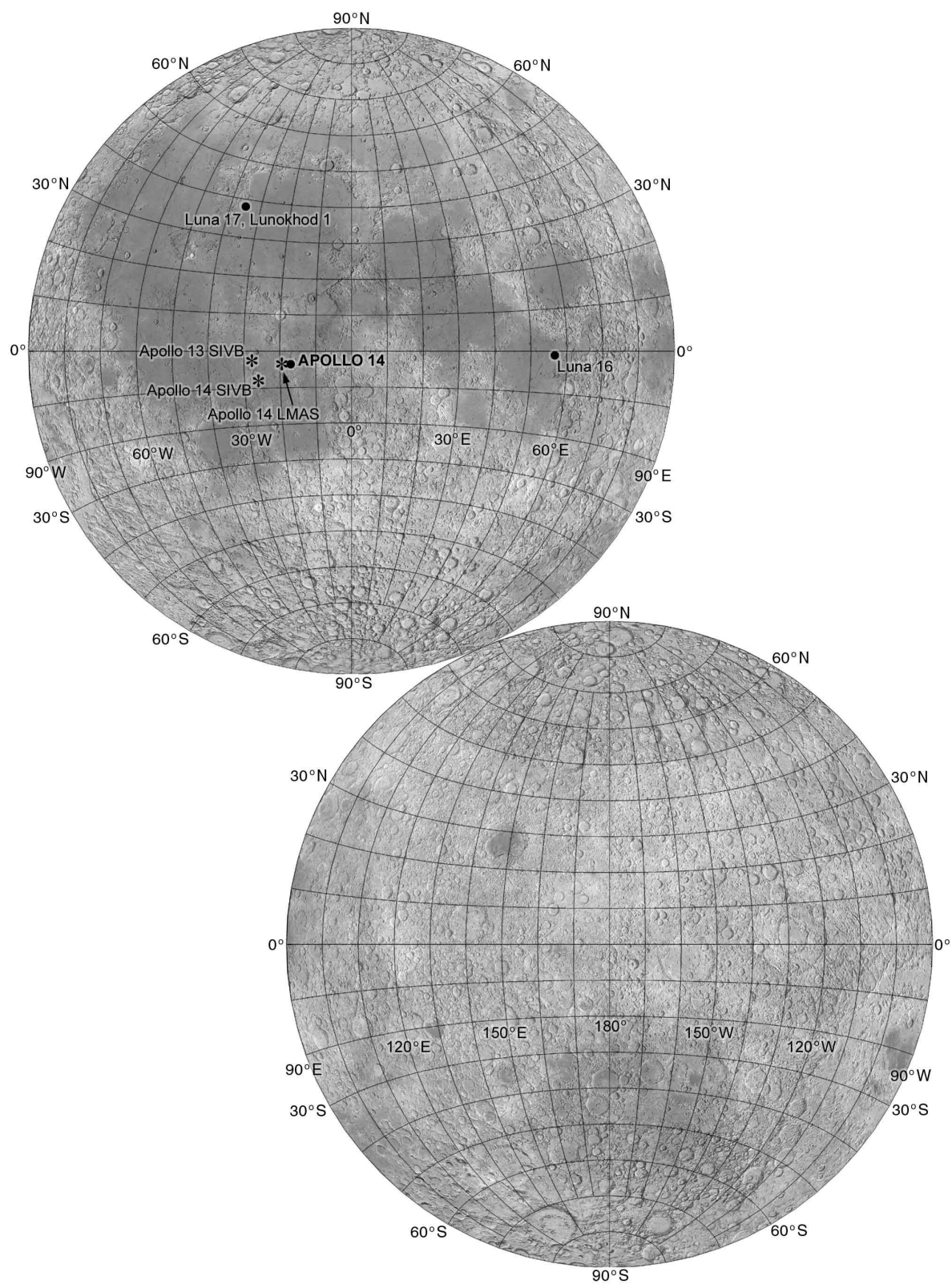


Figure A1. Lunar landings and impacts covered in this volume.